ROSTMOS
ROAD STATE MONITORING SYSTEM
FINAL REPORT
<table>
<thead>
<tr>
<th><strong>Project</strong></th>
<th><strong>Report number</strong></th>
<th><strong>Date</strong></th>
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</thead>
<tbody>
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<td>November 2019</td>
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</tbody>
</table>

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Table of contents

1 Summary .......................................................................................................................... 4
2 General description of the project .................................................................................... 5
  2.1 Background .................................................................................................................. 5
  2.2 Description of the project main objectives and tasks .................................................. 5
  2.3 The projects delimitation ............................................................................................ 7
  2.4 Project impact .......................................................................................................... 7
  2.5 External Consultancy ............................................................................................... 8
  2.6 The final report ....................................................................................................... 8
3 Existing knowledge in the field ....................................................................................... 9
  3.1 Forecasting of road conditions in winter time .......................................................... 9
  3.2 IOT and the future of RWIS ...................................................................................... 9
  3.3 What is a road surface condition? ............................................................................. 11
  3.4 Stationary road weather sensors ............................................................................. 12
  3.5 Mobile sensors for friction and road surface state .................................................. 12
    Mechanical friction testers ......................................................................................... 12
    Mobile road surface state sensors ............................................................................. 13
  3.6 Floating car data (FCD) .......................................................................................... 14
4 Methods ........................................................................................................................ 15
  4.1 Test campaigns ....................................................................................................... 15
  4.2 Equipment .............................................................................................................. 16
    Vehicle dynamics algorithms .................................................................................... 18
    Manual measurements ............................................................................................... 18
  4.3 Denmark ................................................................................................................... 19
  4.4 Norway ..................................................................................................................... 20
  4.5 Sweden ..................................................................................................................... 21
5 Results & Discussion ...................................................................................................... 22
  5.1 Main findings from the reported tests ...................................................................... 22
    Testsite E18 .............................................................................................................. 22
    NTNU 2015-2016 – Appendix B1 ............................................................................ 22
    Bygholm Horsens 2016 .......................................................................................... 22
    Bjorli Airstrip 2015 and 2017 – Appendix B2 ......................................................... 22
    Surnadal 2017 – Appendix B3 ................................................................................ 22
    Bjorli airstrips with surroundings and NTNU lab 2019 – Appendix B4 ................. 23
  5.2 Mobile sensors ....................................................................................................... 23
  5.3 Merging of data and information .......................................................................... 28
  5.4 Recommendations for future tests .......................................................................... 29
6 Concluding remarks ...................................................................................................... 30
Appendix A – State of the art papers .............................................................................. 31
  A1 – Forecasting of road condition in winter time - State of the art ............................. 31
Appendix B – Test campaigns ......................................................................................... 32
  B1 – Norwegian lab tests 2015-16 .............................................................................. 32
1 Summary

Winter maintenance warning stations and road sensors play important roles in both winter service and ITS. In 2014, a 5-year collaborative Nordic project was launched by NordFoU, under the title ROad STate MOntoring System (ROSTMOS), with representatives and experts from Denmark, Sweden, Norway, Iceland, Finland and Faroe Islands (the two last countries from 2015) to map and implement the challenges faced by Nordic road authorities when using sensors. The purpose of the project was formed to develop a system for registration and verification which can accurately monitor the condition of the road network, primarily in real time. The system of registration and verification of road conditions will include data from different sources and will be incorporated into a decision support system where forecasts will be an important element.

Road weather information system (RWIS) have been used with notable benefits since the 1980s in all Nordic countries. During the past few years, we have had several suppliers entering the market with more advanced and more mobile equipment. According to the suppliers, the equipment will be accurate, and it will be possible to measure more parameters in real time. However, after several years of using the equipment, the road authorities in the Nordic region have experienced and pointed out limitations and weaknesses in measurements that have raised concerns among professionals. For this reason, each road authorities in the Nordic region have, through time, established practice and facilities for testing and validating the sensors performance and in particularly precision measurement of the road condition.

Due to lack of time, it was agreed to prioritize the development of a system for verification of road state by use of different types of sensor technologies. This report summarizes the results and experiences from the project. The project has led to a deeper understanding of the strengths and weaknesses of mobile road surface condition sensors. This allows the industry to continue to integrate the sensors in systems for winter road maintenance and ITS. While this report gives an overview of the state of the art, more details about test campaigns, results and recommendations can be found in partial reports written within the project. The main results from each report will be summarized in this document and they are also included as appendices.
2 General description of the project

2.1 Background

Winter road maintenance is performed to reduce the negative impacts of snow and ice on traffic. Since the weather is an important factor in winter road maintenance, measuring systems and maintenance decision support systems are used. This information is also used in order to alert road users about roadway conditions. There exists several types of measurement techniques and sensors that measure weather variables and road surface conditions. Over the last decade new methods for measuring the road surface condition with optical sensors has been more widely implemented. The measurement techniques have also advanced and are now used on vehicles in order to measure entire road networks as well as stationary measurements. The vehicles themselves has also become more advanced both in terms of sensors, algorithms and possibilities for on-board calculations. Information from the vehicles presents new possibilities also for winter road maintenance and projects in this field are ongoing.

The last decade more advanced sensor technology has been developed. Traditional road weather stations measure more variables today than 30 years ago, sensors are installed on maintenance vehicles as well as on public transportation, and dynamic data from vehicles can be recorded and communicated. All these new sources of measurements and observations presents new possibilities for improving winter road maintenance and the general efficiency and safety of road transportation.

The new technology does not only present possibilities but challenges. In order to implement the new data sources, we need to know how reliable and accurate the data is and figure out new ways to implement the information in decision support systems. The data does not only have to be reasonable accurate; it has to be used in an efficient and intelligent manner.

The ROSTMOS project was formed with the aim of developing a system to monitor the condition of the road network in real time. A main objective has been to evaluate the reliability and accuracy of the new technology which has been presented to us. This is seen as the first step to be taken to prepare for full implementation.

2.2 Description of the project main objectives and tasks

Based on several contacts and discussions in communities working with winter road maintenance in the Nordic countries, it has been recognized that there is a consensus on the importance of introducing ITS-systems into a decision support system for winter road maintenance. Thus, it was decided to create a project aimed at pursuing that goal. This report summarizes the NordFoU (Nordic Research and Development) ROSTMOS (ROad STate MOonitoring System) project.
The objective of the ROSTMOS project has been to develop a system for the assessment of road state, that - with high precision - can perform the assessment in near real-time. The system shall be able to operate based on data from various sources and be incorporable into a decision support system, where forecasting the state of the road will be an important element.

Technological is constantly advancing and detection functions are continuously being improved. The goal for the ROSTMOS project is to stay updated on new solutions that can replace or supplement existing technologies and systems that are applied to the assessment of road state.

The ROSTMOS project was originally planned as a three-year project to be executed in the period 2014-2016 with Norway, Sweden, Denmark and Iceland as partners and Norway assuming the role of leading country. In 2016 the NordFoU Steering Committee accepted an extension of the project period with two years, moving the end date to December 2018. Finland and the Faroe Islands joined the ROSTMOS project for the extended project period, i.e. 2017-2018.

The project's overall objective was to identify a system for registration of road state, that with high precision can assess the road state in almost real-time. The system should be able to work on the basis of data from various sources and be incorporable into a decision support system where forecasting of the road state would be an important element.

The project was to demonstrate how road state data can be collected and linked with other information, e.g. information concerning weather condition and operational measures like snow clearing, gritting and traffic volumes, to provide information on the current road state as well as the short-term forecasts of the road state.

The purpose of the project was to develop solutions that can support both strategic and operational decisions made by the road administration, contractors and traffic information centers. An additional purpose was to demonstrate how ITS can be used in quality control and documentation of decisions and of applied winter road counter measures.

Through the project, considerable information and first-hand experience has been gathered, both on national and international level. The project has, through publications and workshops, worked to disseminate this knowledge to all interested stakeholders in the area of winter road management, i.e. road administrations, contractors, manufacturers, suppliers, consultants, etc.

The project was scheduled to deliver the following:

1. A state-of-the-art report on methods and technologies for monitoring the road condition. The report entitled "ROSTMOS - ROAD STATE MONITORING SYSTEM, STATE OF THE ART" has been prepared and updated several times before reaching its final version, see Appendix 3.
2. **Testing and evaluation of various detection methods.** This final report provides an overview of the tests executed in the ROSTMOS project.

3. **Examples of systems for decision support** - status in the Nordic countries and internationally. Preparatory work has been performed but it was decided – due to lack of resources – to postpone this activity to a follow-up project.

4. **Recommendations and proposed architecture for decision support system with different sources for road state information.** See item 3 above.

5. **Information flow - feasibility study and proposed information solutions.** Intended to be an implementation guide, verified through pilot projects. In consequence of postponement of item 3, this deliverable was not realized.

Due to the change in deliverables during the project, the focus and end results have been on the tests the stationary and mobile sensor technology in different environments. Hence, this will be the focus in this report.

2.3 **The projects delimitation**

With reference to the initially objectives, the project decided, due to lack of time, not to pursue the objective related to road state monitoring based on image processing.

Some preliminary work was completed and the project proposes to pursue the original ROSTMOS objective "Road Condition Imaging" in a continuation project to ROSTMOS.

The project has been limited to focus on the practical methods for registration of road surface state by utilizing stationary and mobile road surface state sensors. The different sensors and technologies have been thoroughly evaluated and compared to more established technologies.

2.4 **Project impact**

The project has led to a greater understanding of possibilities and limitations of using mainly mobile road surface state sensors. The results are valuable when the technology will be implemented in practice in the near future. It is probable that larger tests with mobile sensors will take place in the Nordic countries and new projects to cope with the possibilities to use this data in decision support system will be a theme in future projects.
2.5 **External Consultancy**
The project has used consultancy services form as follows:
- Johan Casselgren, Luleå Technical University
- Johan Wåhlin, Trondheim University (NTNU)
- Mats Riehm, consultant
- Lars Forslöf, consultant at Etex AB
- Karl Schedler, consultant

2.6 **The final report**
In a practical sense, the starting-point for the project has been the road surface, and to be more specific, how we can measure the road surface state. Accuracy, reliability and repeatability of the measurements must be thoroughly evaluated before the sensors can be used in practice. Since there was a lack of thorough tests of mobile road surface state sensors, this has been this efforts main focus. During the project, several literature reviews were conducted. The purpose of these reviews has been to describe intelligent traffic systems, how road surface data can be used, and the what types of sensors the market offers today.

The following chapters uses the same working logic as the project implementation. The next chapter will give a summary of the literature studies and state-of-the-art. Chapter 4, Methods, will describe the methods and measurement campaigns used for evaluating the mobile sensors which has been the main focus within the ROSTMOS project. Chapter 5, Results and Discussion, will summarize the results from the testing campaigns as well as discussing possible implementation and next steps in order to implement the results and technology in the next generation road weather information systems and maintenance decision support systems. Finally, in chapter 6, the main conclusion will be summarized.
3 Existing knowledge in the field

The ROSTMOS project has initiated several state-of-the-art studies which now will be presented. The intention has been to describe the state of the art of forecasting, different types of sensors and intelligent traffic systems (ITS).

<table>
<thead>
<tr>
<th>Forecasting of road condition in winter time - State of the art</th>
<th>A1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Weather information and the “internet of things” (IOT)</td>
<td>A2</td>
</tr>
<tr>
<td>Road state monitoring system – State of the art</td>
<td>A3</td>
</tr>
</tbody>
</table>

Table 1. State of the art documents created within the ROSTMOS project.

There is a growing consensus internationally that ITS applications have great potential to make winter operations more effective and efficient. However, to improve winter road maintenance has not been a driving force so far, and the potential is far from exploited.

3.1 Forecasting of road conditions in winter time

The market for forecasting road conditions is not as regulated as it is for equipment. There is no standard and most applications are ‘spin offs’ from ordinary weather prediction system. This is most likely a consequence of that equipment is manufactured by private companies whereas forecasting traditionally has been a national responsibility. During the last years there has become consensus off what the basic requirements are for a forecasting system for winter road conditions.

Forecasting of road conditions is an established science in the sense that all processes are well understood. However, compared to more traditional weather forecast the focus is on the roadway surface rather than on the near surface air conditions which is the main focus in more traditional weather prediction. One way to establish methods to predict conditions on the road surface, has been to try various methods to produce a more specialized product for exactly this problem. This attempts to optimize the forecast quality of the road conditions with special focus on the road surface temperature and the amount of water and ice on the road.

Models for road condition, as well as a presentation of the meteorological principles and forecast systems, are elaborated in appendix A1.

3.2 IOT and the future of RWIS

New ways to gather and receive data has creates new possibilities for data collection in several fields. In the development of 5G, and low power communication techniques such as LoRaWAN (Long Range low-power wide-area network) the term
internet of things (IOT) has become a common term to describe the general direction of the new techniques and possibilities.

Intelligent traffic systems (ITS) are wide-ranging and there are several examples in areas where ITS is being used to support winter maintenance operations. The international focus in this area has been directed towards the development of decision support systems where weather data is an important input. Another example, are systems for recording driving conditions where the measurement of friction and wireless transmission of measurement data clearly can be labeled ITS.

Another area that may be mentioned are systems for automatic data collection that has been in use for a number of years. Automatic data collection is also an example of a system that itself is not "intelligent" before the data is used for active management of winter operations and included in a decision support system. Real-time information about driving conditions linked to weather stations and condition data from mobile vehicle systems are ITS measures enable maintenance to take action in the right place at the right time using right method and with proper level of effort.

Real-time road state data is also an example of ITS applications that can work in different ways. While this data can come from cars that act as sensor systems, this will be the data that may be included in the information systems that is sent data back to the road users, and thus has a major potential to improve traffic safety. This kind of two-way communication falls under the concept of cooperative systems which is one of the growth areas for ITS applications.

Future development will likely show how IOT and crowd sourced input from car sensors will be implemented and to be used as an addition, not replacement, for road weather stations. A common infrastructure that serves multiple uses would help to strengthen the distribution and implementation of ITS measures, which also is an international trend. Appendix A2 presents some example of current and future development within IOT and ITS connected to winter road maintenance.
3.3 What is a road surface condition?

Road surface condition and friction is the information that needs to be measured and communicated to the road weather systems. To define “road surface conditions” is not as trivial as it might sound. A road surface condition is a description of the road surface and its state but in order to define such descriptions there has to be something that is measurable and can be described in numerical values. Typical road surface conditions relevant to winter road maintenance includes dry, moist, wet, ice, snow or hoar frost. But some manufacturers use even more terms such as “chemical wet”, indicating that residual salt is present on the road, or “critical wet” when there is a water depth which could lead to aqua planning. The challenge is that there is no standard shared between the manufacturers or road weather sensors. Hence, two different sensors can report moist and wet at the same time and both could be correct according to their own definitions. It is a matter of how the thresholds are defined.

Due to the challenges of defining road surface conditions, observer who evaluate the sensors typically uses road surface states which are indisputable. Such as a very dry road or a road which is clearly frozen with clear ice or snow covered.

A road condition could also be attributed to friction; a definition and means for measurement of friction will be presented in chapter 4.4. Friction is typically reported as a numerical value between 0 and 1 where a value of 0 means there is no friction at all and a value of 1 means the friction is equal to normal force. These numerical values have been reported as information for maintenance personnel and airports, but the trend within airport maintenance is that a simplified 1 to 5 code system will be adopted where 5 means “good estimated braking action”. If this development translates in the winter road maintenance industry in the future, we will see the same challenges as for other road surface conditions since descriptive words for grip needs to have numerical thresholds.
3.4 Stationary road weather sensors
Standard sensors and road weather stations are readily available from a number of international suppliers. Several of the sensors are also used for meteorological stations but some of the sensors are specifically used for road application. Appendix A3 provides an overview of state-of-the-art commercially available equipment used to assess the road surface condition. The overview includes both invasive and noninvasive equipment and mobile as well as stationary equipment.

3.5 Mobile sensors for friction and road surface state
Methods for measuring road surface state condition and friction includes optical non-intrusive sensors and mechanical friction testers. The later has been used in practice for many years and has been used as a reference for friction within the project.

Mechanical friction testers
The traditional method for measuring the friction on roads and airport runways has been to use friction testing vehicles or trailers. In Norway, friction measuring trailers from ViaFriction is used as standard (figure 1). The trailers measure the friction between a measurement wheel and surface continuously. The friction testers have been used as reference for the mobile sensor as it is a technology which has been thoroughly tested in the past and shown to be repeatable and reliable.

Figure 1. Trailer for mechanical friction measurement with two friction wheels. (Bjorli test arena, 2019)
**Mobile road surface state sensors**

Mobile road surface state sensors for winter road maintenance has been tested in practice for over a decade. Performing the measurement from a moving vehicle is much more challenging as compared to the stationary application for a variety of reasons. The variation of the road surface makes it more challenging for the algorithms to calculate the road surface state compared to a stationary application where the dry surface is a constant which can be used for calibration. Furthermore, a mobile sensor is exposed to dirt and water from the road surface and consequently must be well protected and kept cleaned.

The value of a mobile measurement, which not only describe a single point but a road stretch, are so important high that several manufacturers has spent effort to develop mobile road surface state sensors. Manufacturers including Lufft, Teconer, Metsense and Vaisala and the sensors from these four brands have been included in the ROSTMOS-project. Since the Vaisala’s MD30 sensor just recently came to the market it has not been evaluated for as long as the other sensors. All the brands face some common challenges and limitations, but it is believed that progress will be made both regarding the actual measurement, data processing and physical properties to further develop the sensors.

Mobile road surface state sensors are also important for the aviation industry and it therefore of interest of the road maintenance industry to also follow the progress of measurements on airports where the same type of technology is implemented but the challenges might be different. One goal for the project has been to evaluate the sensor technology of mobile road surface state sensors in order to achieve a better understand of the accuracy, repeatability and reliability of the measurements.

![Figure 2. Lufft MARWIS mounted on testing vehicles.](image)

The non-invasive road surface state sensors use the same fundamental physics of spectroscopy. This is the study of interaction between matter and electromagnetic radiation (such as light). The theoretical foundation is simple using visible or non-visible light that emitted towards the surface. Depending on the surface properties and what lies on the surface, a portion of the light is absorbed or reflected. The
instruments emit light by using, for example, a LED, Halogen, laser, and the back scattered light is detected and measured by a near infrared detector or camera. Since the wavelengths that are susceptible to be more or less absorbed by water, ice and snow are within the near infrared spectra, the manufacturers often use filters or specific lasers to achieve different absorptions as the road condition changes. While variations exist in this approach, it is the basic measurement principle for both the stationary and mobile road surface state sensors.

The aim of this report is not to describe the measurement technologies in detail, but the basic principles. This is seen as important to better understand the possibilities and limitation of the technology which will be further discussed in the results section.

3.6 Floating car data (FCD)

Since the 1990’s, vehicles using the road network have been equipped with an increasing number of driver support systems like ABS, rain detection, air and road surface temperature, etc. Some of these support systems can supply direct measurements of selected road weather parameters or supply information on such parameters derived from other information as acquired by the system.

In the beginning of the 21’st century, legislation was passed, first in the USA and later in Europe, requiring that all road vehicles should implement an OBD2 interface providing access to vital operation and maintenance information. The purpose of this legislation was, in part, to allow easy inspection of vital operational parameters (e.g. emission data) and, in part, to stop vehicle manufacturers monopolizing required service tasks on their own products. The OBD2 was implemented “on top of” the CAN-bus, a data bus that automakers had been using for some years as the communication backbone in vehicles. This was in order to reduce the amount of wiring required to make vehicles populated with an increasing number of electronic subsystems (e.g. EMU, ABS, SRS etc.) work without extensive direct cabling between units.

Several systems for floating car data are under development and used in full scale tests. Some of these are targeting aspects of winter road maintenance.
4 Methods

The methods chapters will describe the test campaigns, equipment and the respective test site.

4.1 Test campaigns

For testing instrumentation in general, tests are conducted in several stages with the degree of control of the environment being less in each stage. In the ROSTMOS-tests, three stages have been used:

1. Laboratories with full control over the environmental conditions
2. Closed road stretches or air strips with control over traffic and maintenance actions
3. Public roads with no control over traffic or environmental conditions

![Figure 2. The three types of tests conducted within the ROSTMOS-project.](image)

The three types of tests are all crucial to understand the best possible performance under ideal conditions (laboratory) as well as the instruments reliability and repeatability in actual winter conditions on trafficked roads (see figure 2). The lab tests give an understanding of the inherent measurement uncertainties and build in limitations of the measurement principles. These limitations will also be present as the tests are continued on the roads. Not until tests have been conducted in those different environments, can the end user be assured that the instrument is ready for implementation.

The tests within the project has been conducted in the three types of listed environments to fully understand the characteristics and reliability of the different measurement principles and instruments. While all countries within the project are involved in
testing new technology for winter road maintenance, the majority of test campaigns within the project have occurred in Denmark and Norway. In table 1, the ROSTMOS testing campaigns are listed with details about the aspects of the of testing in regard to controllability of the type of the sensor technology being tested.

<table>
<thead>
<tr>
<th>Test ref. #</th>
<th>Site</th>
<th>Country</th>
<th>Lab or road</th>
<th>Winter month</th>
<th>Stationary sensors</th>
<th>Mobile sensors</th>
<th>Report</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Testsite E18</td>
<td>Road</td>
<td>2010-2010</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>NTNU, Trondheim</td>
<td>Lab</td>
<td>2015-09</td>
<td>No</td>
<td>Yes</td>
<td>[B1]</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bjorli airstrip with surroundings</td>
<td>Road</td>
<td>2015-12</td>
<td>No</td>
<td>Yes</td>
<td>[B2]</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Bygholm, Horsens</td>
<td>Air strip</td>
<td>2016-01</td>
<td>Yes</td>
<td>Yes</td>
<td>[B3]</td>
<td></td>
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<tr>
<td>5</td>
<td>Surnadal/Rindal</td>
<td>Road</td>
<td>2017</td>
<td>No</td>
<td>Yes</td>
<td>[B4]</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Bjorli airstrips with surroundings and NTNU lab, Trondheim</td>
<td>Lab and road</td>
<td>2019-02</td>
<td>No</td>
<td>Yes</td>
<td>[B5]</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Summary of tests conducted within the ROSTMOS project.

In the results and discussion section, the main results from each respective testing campaign will be presented along with a discussion from the overall picture resulting from all tests. The details of the listed testing campaigns can be found in the respective reports listed in the rightmost column in table 1.

In addition to the main tests listed in table 1, the project stakeholders have performed smaller tests and evaluations since the initiation of the project. The results have been communicated within the project but the project details will not be repeated in this report.

4.2 Equipment

The main focus within the ROSTMOS-project has been to test and evaluate different sensor technologies for winter road maintenance. The purpose has been to evaluate if, and how, these instruments can be implemented in winter road maintenance and maintenance decision support systems. In order to do this, the three stages of testing (figure 1) have been conducted.

During the last 10 years, mobile sensor technology has been adopted to an increasingly greater extent. The project stakeholders have a common interest in increasing the knowledge on the measurement accuracy and in user scenarios for the implementation of these different instruments. Hence, the project team chose to include several mobile sensors from different manufacturers. Since the usage of stationary sensors is the current best practice for winter road maintenance measurements, instruments at stationary sites have been included in the test, mainly as calibration
references for the mobile sensors. The majority of sensors used in the ROSTMOS-project are listed in table 2.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Name</th>
<th>Stationary or mobile</th>
<th>Measurement variables</th>
<th>Used in test campaign (Reference to table 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaisala</td>
<td>DSC111/211</td>
<td>Stationary</td>
<td>Road surface state and friction</td>
<td>#2 and #4</td>
</tr>
<tr>
<td>Vaisala</td>
<td>DST111</td>
<td>Stationary</td>
<td>Road surface temperature</td>
<td>#4</td>
</tr>
<tr>
<td>Vaisala</td>
<td>DRS511</td>
<td>Stationary</td>
<td>Road surface temperature, surface state, freezing point</td>
<td>#4</td>
</tr>
<tr>
<td>LUFFT</td>
<td>IRS31</td>
<td>Stationary</td>
<td>Road surface state, road surface temperature, friction</td>
<td>#4</td>
</tr>
<tr>
<td>MetSense</td>
<td>2D Road</td>
<td>Stationary</td>
<td>Road surface state in 2D</td>
<td>#2</td>
</tr>
<tr>
<td>Lufft</td>
<td>MARWIS</td>
<td>Mobile</td>
<td>Road surface state and friction</td>
<td>#2, 4, 5 and 6</td>
</tr>
<tr>
<td>Teconer</td>
<td>RCM411</td>
<td>Mobile</td>
<td>Road surface state and friction</td>
<td>#2, 4, 5 and 6</td>
</tr>
<tr>
<td>MetSense</td>
<td>MetTemp Mobile</td>
<td>Mobile</td>
<td>Road surface temperature</td>
<td>#2</td>
</tr>
<tr>
<td>MetSense</td>
<td>MetRoad Mobile</td>
<td>Mobile</td>
<td>Road surface state</td>
<td>#4 and 5</td>
</tr>
<tr>
<td>Vaisala</td>
<td>MD30</td>
<td>Mobile</td>
<td>Road surface state, friction, road temperature, air temperature, relative humidity and dew point</td>
<td>#6</td>
</tr>
</tbody>
</table>

Table 2. Sensors, Mobile as well as stationary, used within the ROSTMOS project.

The sensors listed in table 2 are all designed for measuring variables specifically for winter road maintenance. In addition to the listed sensors, the project has also used sensors for meteorological variables such as air temperature, wind, humidity and precipitation. These are all fundamental variables for road weather stations and are typically measured at all test sites. Road weather stations are normally equipped with these basic meteorological variables. At a minimum, the road surface temperature can be measured both with embedded sensors such as DRS511, IRS31 or a PT-100. The road surface temperature can also be measured by non-invasive sensors using infrared thermometry to measure the thermal radiation of the road’s surface which is directly proportional to the road’s surface temperature. All non-invasive road surface temperature sensors shown in table 2 use infrared thermometry. To measure road surface temperature is not trivial and will be briefly discussed in chapter 5 (results).
<table>
<thead>
<tr>
<th>Type of measurement</th>
<th>Description of measurement</th>
<th>Used in test campaign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle algorithms</td>
<td>Calculations within a vehicle based on vehicle sensors and information. Friction estimates, precipitation (usage of wipers) and several other variables are available.</td>
<td>#7</td>
</tr>
<tr>
<td>SOBO20</td>
<td>Manual measurements of residual salt per square meter.</td>
<td>#4</td>
</tr>
<tr>
<td>“Wettex”</td>
<td>Water is absorbed from the surface and weighted to estimate amount of water per square meter.</td>
<td>#4</td>
</tr>
<tr>
<td>Camera pictures</td>
<td>Pictures of road surface from stationary camera or vehicle.</td>
<td>Used in all tests.</td>
</tr>
<tr>
<td>Image analysis</td>
<td>Extracting of information, such as road surface state, from pictures by image processing techniques.</td>
<td>-</td>
</tr>
<tr>
<td>Handheld IR-thermometer</td>
<td>Device for indirectly measuring the surface temperature by measuring thermal radiation.</td>
<td>#4</td>
</tr>
</tbody>
</table>

Table 3. Additional data sources used in the ROSTMOS project.

In addition to the listed sensors, camera pictures have been used from stationary road weather stations as well as from vehicles. In table 3, additional sources of information have been listed.

**Vehicle dynamics algorithms**
Normal passenger vehicles carry a lot of information from on board sensors. Information like windshield wipers usage, ambient temperature and electronic stability programs such as traction control can be processed and communicated to other vehicles or central data centers. The information could be used for winter road maintenance since it gives an indication of where on the road network there would be precipitation or slippery conditions. The strength of this idea is that the large numbers of cars would produce large data sets which, if used as an aggregate, could add information on current road weather between stationary road weather stations. This is a very powerful concept but comes with some challenges such as privacy, quality of data and the need to develop business models in order to implement the technology and make it fully usable.

Within the ROSTMOS project, the company NIRA Dynamics, in February 2019, was involved to test and demonstrate their algorithms for vehicle dynamics. The NIRA dynamics algorithms estimate the tire-road friction from vehicle dynamics and sensors. The system has seen increased accuracy at times when the ABS or stability system (i.e. ESP) is active. The friction estimations from NIRA are provided through the Tire Grip Indicator. It should be noted that Volvo Cars also have used the Bjorli test arena for testing of their algorithms for vehicle dynamics, but this has not been reported as part of the ROSTMOS project.

**Manual measurements**
At test sites where the traffic can be controlled, such as Bygholm in Denmark, manual measurements of road surface moisture and residual salt have been used.
4.3 Denmark
In Denmark the following test campaigns have been executed:
- two tests at the Bygholm Test Track
- one test on the Holbæk motorway
- one test at the Osted test site

The majority of the tests were conducted at the Bygholm Test Track, figure 2. The test track is used for tests in which traffic can be simulated in a controlled manner in order to create a realistic road environment with traffic but with the possibility to safely perform measurements by stopping the traffic. The test vehicles are driven by test personnel and is thereby controlled both in terms of speed and frequency.

Figure 3. Bygholm Test Track.

The Bygholm Testsite has a number of road weather sensors from Lufft and Vaisala (Table 2). The sensors include both road embedded and non-intrusive technology.
4.4 Norway

In Norway, the Bjorli test arena was used for several of the measurement campaigns. The test arena has several areas with different properties, all of them free from public traffic. Compared to the Bygholm test site, Bjorli has areas with both curves and slopes, figure 4. The paved testing tracks are:

1. Flyplassvei: linear test track with two lanes and turning place on each end.
3. E136 and Rånå: small road connecting the test site with public road with different slopes.

Figure 4. Bjorli testing site
4.5 Sweden
Test site E18 is a permanent test site situated 90 kilometers west of Stockholm at European highway E18, figure 5. The permanent road weather stations are mainly used for on-going measurements of road weather and environmental factors such as water quality and run off water. The site is also used for test campaigns where mobile or manual measurements are used in order to conduct more detailed tests or to validate the permanent sensors. Over a period of 7 years, the site has had permanently installed road weather stations from five different suppliers. The road weather stations include non-invasive road surface state sensors from Vaisala, Lufft and Boschung as well as several different types of sensors embedded in the road surface. The site has been used for evaluating different sensors and will continue to be used for this purpose in the future.

Figure 5. Road weather stations at Test site E18.
5 Results & Discussion

5.1 Main findings from the reported tests
The main findings from the respective field campaign are listed below. In chapter 5.2 the results are discussed in a broader sense.

Testsite E18
No separate report has been presented from the tests at Test site at E18. This site is mainly used for tests of stationary sensors which has not been the focus for this project. The site will be in continuous operation in the future and will be used for other projects concerning winter road maintenance.

NTNU 2015-2016 – Appendix B1
In the tests at NTNU, Trondheim, several optical sensors were tested in a laboratory environment. It was concluded that road surface condition classification works very well for homogeneous conditions. Snow was proven to be more complex since there are different types of snow.

Water film thickness was correct within a factor of 5. While this might sound large correction, this level was concluded to be good enough to be useful for estimating water amount on a road.

Friction estimates are based on the surface classification. Consequently, friction estimates were misleading in the cases the sensor was not able to correctly classify the surface. However, as long as the sensors could classify the road surface, the friction estimates were reasonable. Finally, it was concluded that optical road condition sensors are reasonably reliable tools for use within winter road maintenance.

Bygholm Horsens 2016
Extensive testing or optical road surface condition sensors were conducted.

Bjorli Airstrip 2015 and 2017 – Appendix B2
In the Bjorli tests of 2015 and 2017 the tests were conducted in actual road environment and benchmarked against other technologies. It was concluded that the optical sensors correlate with methods like Roar and ViaFriction (mechanical friction measurement). Due to the low price of optical sensors compared to mechanical equipment, the sensors can be installed in greater number, such as within public transportation.

Surnadal 2017 – Appendix B3
The tests around Surnadal was conducted in the actual road environment. During the tests several challenges with the friction estimations were identified. It seemed like the friction was generally reported as too high and did not correlate with mechanical measurements. This was somewhat contradictorily to the conclusions at Bjorli. However, a reason for this might have been that some of the tests were conducted at
gritted road stretches. While the mobile sensors will detect the road surface condition on gritted roads, the estimated friction values will differ from the actual friction due to the effect of the gritting.

**Bjorli airstrips with surroundings and NTNU lab 2019 – Appendix B4**
In this last of the Norwegian tests, both laboratory and roads were used. Experiences from previous tests were considered. In addition to optical sensors, vehicle algorithms from NIRA Dynamics were also tested. It was concluded that both the sensors and the vehicle algorithms show reasonable friction estimates compared to the friction measurement from mechanical devices. The road state condition classifications were comparable with the visual observations for all road surfaces states but would not detect grit.

### 5.2 Mobile sensors
Several brands of mobile road status sensors have been tested and evaluated within the project. As with all sensor, mobile sensors have limitations. Since the manufacturers are constantly trying to improve their products, the objective has not been to try to score the sensor against each other. This information would soon be out of date, since the manufacturers are continuously improving their products. Instead the project has tried to describe possibilities and limitations which are common for all sensors.

The main objective of the tests has been to evaluate the sensor technology and how it can be implemented in road weather information systems. The tests were conducted in the three different types of environments discussed in section 5.1 and the extensive testing has led to a good understanding of the possibilities and limitations linked to mobile road surface state sensors. The mobile sensors have several strengths and weaknesses which makes them fundamentally different to implement compared to traditional measurement techniques. Some of these strengths and weaknesses are listed in [figure 6](#). The listed characteristics are common between all the different brands of sensors, but each model has its own additional strengths and weaknesses.
We will describe each strength and weakness. The first listed strength, the ability to detect small amounts of ice and snow, is extremely important and one of the main reasons the technique is so useful. Very thin layers of water are required for the roads to become slippery as they freeze. Hence, it is crucial to be able to detect even the smallest of dew depositions. The sensors generally detect small amounts of moisture, and the same goes for frost. The result is not surprising since stationary sensors using the same technique have shown good results in field conditions in both tests and in full scale deployment in several countries. Due to the ability to detect very thin layers of moisture, the sensors have an early warning capability and are able to detect water amounts that are barely visible to the eye but important from a winter road maintenance perspective.

Since the sensor technology is fast since it technically can quickly emit and measure reflected light, it is possible to measure conditions with a high spatial resolution i.e. short distance between each measurement spot even if the vehicle is driving at normal speed. This produces very detailed information on how the road surface state is changing over shorter road stretches more prone to ice formation, such as bridges. The high spatial resolution is also a very powerful data set to feed into forecasts and maintenance decision support systems.
The sensors need to be installed within a specific height and angle. But nevertheless, the installation on vehicles is simple and the suppliers are supportive and can help with equipment and instructions. The current sensors are too large and cumbersome to be installed on private vehicle in great number, and this is not the purpose. Since some care must be taken to keep the lenses clean, the instruments are designed for professional users only. In the future, smaller optical sensors might be adopted for private vehicles, but it is probable that this technology will look different and be used in conjunction with other data source from the vehicle and will be processed in the vehicle.

The sensors are affordable for usage for winter road maintenance. Since they can be purchased at a lower cost than mechanical friction sensor, and requires less from the operator there is a good chance that these types of sensors may be used more widely in the future. Hence, it is important to continue to evaluate the sensors and find ways of using the data to its highest potential.

One of the fundamental differences between the estimated friction from a mobile sensor and a mechanical friction tester is that the estimated friction is based on what the sensors “sees” while the mechanical measures what it “feels”. This means that the mobile sensors might report water even though there is ice under the water film. This situation might not be very common but since the consequences might be severe it must be noted. For the same reason, the mobile sensors are not good at estimating friction on gritted roads and it is not realistic that they can do so either. However, the sensors can still detect the overall road surface state even on gritted roads and be very useful for this purpose.

As shown in all tests where mobile sensors were compared to mechanical friction testers there, is a correlation between the mobile sensors and friction testers. Both the estimated values from the sensors and the measured values from the friction testers will report lower friction as the road goes from dry to wet and icy. However, the numerical values generally differ substantially. Since the estimation and measurement are so fundamentally different, this was expected. The mobile sensors often tended to estimate higher friction than was measured. Due to this, future users, should not focus too much on the numerical friction estimates. The values are estimations by the use of algorithms and hence should be treated as such.

The resolution of the friction values is reported with two decimals and gives an impression of very specific changes in estimated friction. In practice, it could make more sense to report “classes or categories” of grip. This would follow the same reasoning as in the aviation industry where reporting formats currently are planned to be changed from measured friction coefficients (numerical value) to “estimated braking action” in five classes ranging from poor to good. This could also be adopted by the road maintenance communities in the future, but if so, we must not forget that the same challenges appear as for road condition classification; What does “good braking action” or “wet road” actually mean? The definitions of road surface states are also different between the sensors and it could be argued that a standardization of
road surface conditions would be useful for the industry. If the numerical values are to be used the users must be aware of the variability and accuracy of the measurement as well as in which situations the measurements are not valid. If so, numerical values could still be used and for example visualized in maps.

It is important to note that the mechanical friction testers are not a perfect reference and has its own limitations. The measurements will never be precisely representative for passing vehicles for reasons summarized in figure 7.

Since the measurement areas are rather small the measurements will not be representative of the whole road. Depending on how the sensor is installed on the vehicle the sensor will measure in wheel tracks or in-between track. Since the sensors are relatively cheap some users will consider installing two sensors in order to measure both in and besides the wheel track. The measurement area is also different between the brands and will also differ depending on how far from the surface the sensor is installed. In that respect, using sensors from the actual vehicles makes sense since

Figure 7. Examples of differences between measured friction and actual car braking action.
they are based on the actual vehicle behavior and tire grip. Some manufacturers are also looking into making 2D-sensors which scans the entire width of the road.

The overall conclusion, which is the most important result, is that mobile road surface state sensors have reached a level of quality and accuracy which meets the high requirements of winter road maintenance personnel. It has been concluded that friction estimates from mobile road surface state sensors correlates well with physical friction measurement devices. Furthermore, it has been concluded that the mobile road surface state sensors in general are also able to classify road surface conditions when compared with manual observations and camera pictures. The project can therefore conclude that mobile sensors can be useful within winter road maintenance as a complement to stationary stations. The user cases include, but are not limited to:

- Installation in vehicle fleets and maintenance vehicles to be used as input in maintenance decision support systems
- For measuring the prevailing road surface states while performing maintenance actions
- For following up maintenance actions to ensure that the actions have achieved satisfactory results
- Implementation in intelligent traffic system

The sensors are meant to be complementary with road weather stations and fill the spatial information gap between the stationary stations. The stationary road weather stations are still needed and are important to achieve continuous time series with high measurement accuracy.

In some countries, such as in Norway, friction measurements are conducted using friction wheels. Since the mobile sensors estimated friction values correlates well with the friction wheels there could be situations where the users could consider using mobile sensors instead, especially in the salted parts of the road network. However, the fundamental differences between estimating and measuring the friction must be accounted for.
5.3 Merging of data and information

Maintenance decision support systems aim to combine data and information from various sources in order to be able to produce the best forecasts and suggestions for maintenance actions. During the project the view has been, and remains, that stationary road weather stations still play an important role in winter road maintenance. The reasons, as has been mentioned previously, are that the road weather stations are able to continuously feed the forecast models without interruption or dependency of an operator while mobile sensors are dependent on a moving vehicle.

It is believed, and has been a theme in several ongoing projects including the ROSTMOS project, that floating car data (FCD) will act as an increasingly more important source for data to maintenance decision support systems. As has been demonstrated in the test campaign in Norway 2019, data processed from build-in vehicles sensors can also be used to estimate friction values. In next generation maintenance decision support systems, it is likely that road weather stations, mobile sensors and floating car data will be merged and used together to deliver the best possible forecasts and suggestions for maintenance actions (figure 8). It is possible that the development of mobile sensors progresses into integrating the sensors into vehicles but for the future it is thought that separate sensors for professional use in combination with road weather stations and FCD will be the best practice.

Figure 8. Merging of data and information within winter road maintenance.
As more data and information is being used, the administration of the systems will be much more complex compared to the current generation of road weather information systems. Today’s systems generally use stationary road weather stations, owned and maintained by the road administration or regions. The data from the station is sent and collected at a central server where it can be in combination with meteorological forecasts to feed the road surface state forecast models and maintenance systems. As more information is introduced into the models, for example from private cars, the demand for new business models as well as administrative and legal frameworks will be required. These administrative and commercial challenges are likely to become as important as the technologies themselves in order to implement the next generation road weather information systems. Since data and service tend to merge, there will be more focus on service providers rather than technology.

5.4 Recommendations for future tests
During the test campaigns there were numerous incidents with instruments which short circuited or for other reasons did not record measurements. In future tests, it is recommended to double the number of instruments i.e. have at least two units of the same instrument on each station or vehicle to achieve redundancy. Tests are expensive and involve a lot of planning and resources. Hence, test campaigns failing due to problems with single instruments are not acceptable and can be avoided through redundancy.

The project had great use of laboratory measurements. These controlled measurements give a good understanding of the sensor’s limitations and best possible measurement accuracy under controlled conditions. It is thereby easier to understand what level of accuracy can be expected in the less idea the road environment. Hence, the project recommends future projects to use laboratory tests for instruments which are new in terms of design and/or measurement principle.
6 Concluding remarks

During the project period, extensive tests using mobile road surface state sensors have been completed. The tests have shown that the sensor technology is reliable enough to be implemented for winter road maintenance. The mobile sensors have at least three use cases within winter road maintenance: 1. For installation in vehicle fleets i.e. public transportation and maintenance vehicles to feed decision support systems with valuable spatial data. 2. For measuring the prevailing road surface states while performing maintenance actions. 3. For following up of maintenance actions to ensure that these actions have achieved satisfactory results.

In general, road condition classification works well for mobile road surface condition sensors. Some limitations have been discussed but as long as these limitations are accounted for, the sensors can be a very valuable tool for winter road maintenance.

The testing devices (mobile road sensors and NIRA dynamics algorithms) show reasonable friction estimations compared to the mechanical friction measurements. The road state condition classifications are comparable with visual observations. Road authorities should not be overconfident in either the measured or estimated friction values due to the previously discussed limitations. Rather, values should be grouped into classifications rather than focusing on decimals. The estimates are based on algorithms and the underlying measurement of the road surface condition and depth of the water or ice.

One major advantage of the non-intrusive sensors is that they have a lower price than system such as the mechanical friction devices Roar and ViaFriction so the sensor could be deployed in a larger scale and on public transportation fleets such as postal vehicles or busses. This also gives a more environmentally friendly impact as there special vehicles are not necessary to do measurements.

Since the ROSTMOS project has shown the reliability of mobile sensors and presented their strengths and weaknesses, future projects should focus on implementing the measurements in systems such as maintenance decision support. This should be synchronized with the current developments within floating car data as well as other projects connected to the next generation road weather information systems.
Appendix A – State of the art papers

A1 – Forecasting of road condition in winter time - State of the art
A2 - Road Weather information and the “internet of things”
A3 - ROSTMOS SOTA
Appendix B – Test campaigns

B1 – Norwegian lab tests 2015-16

B2 – Norwegian field tests 2015 and 2017

B3 – Danish field tests at Bygholm 2016

B4 – Norwegian field tests Surnadal 2017

B5 – Norwegian field and lab tests 2019