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Report

A feasibility study for road and weather information and variable speed limits

Authors
Trond Foss
Isabelle Roche-Cerasi
Petter Arnesen

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SINTEF

SINTEF Teknologi og samfunn
SINTEF Technology and Society

Address:
Postboks 4760 Sluppen
NO-7465 Trondheim
NORWAY

Telephone:+47 73593000
Telefax:+47

ts@sintef.no
www.sintef.no
Enterprise /VAT No:
NO 948 007 029 MVA

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AUTHORS
Trond Foss
Isabelle Roche-Cerasi
Petter Arnesen

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Torgeir Vaa and Kai Rune Lysbakken

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ABSTRACT

This report presents the state of art on the development of ITS applications

- informing travellers about weather and road conditions that may cause an increased risk level concerning traffic safety, and
- reducing the speed limit when visibility and road conditions are impaired by bad weather conditions.

The report describes information systems and variable speed limits in 8 different countries that have winter conditions similar to the Norwegian winter conditions. Collection of weather and road surface conditions at the 4-lane motorway E18 in Vestfold, Southern Norway, is used for a more detailed case study. The correlations between the remote friction sensors values and the thickness of water, snow and ice on the road surface are studied as well as between the friction and the speed selected by the drivers. The report also includes a proposal for variable speed limits based on friction and some recommendations for future work.

The work documented in this report is part of WP03 on ITS and decision support in the EVI Research program.

PREPARED BY
Trond Foss

SIGNATURE
Trond Foss

CHECKED BY
Terje Moen

SIGNATURE
Terje Moen

APPROVED BY
Roar Norvik

SIGNATURE
Roar Norvik

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Table of contents

APPENDICES

[List appendices here]

Preface

The project documented in this report has been accomplished on the request of the Norwegian Public Roads Administration, Road Directorate. The client has been represented by Torgeir Vaa and Kai Rune Lysbakken. SINTEF Technology and Society, Transport Research Department has been responsible for the content of the report. Trond Foss has been the project manager and both Trond Foss, Isabelle Roche-Cerasi and Petter Arnesen (all SINTEF employees) have contributed to the report. Terje Moen, SINTEF, has been responsible for the quality assurance.

Trondheim, December 2016

SINTEF Technology and society
Transport research Department

Roar Norvik

Roar Norvik

Research Director

Summary

The construction of highways with high speeds and traffic volumes increases in Norway. Speed limits are consequently increased from 90 and 100 km/h, up to 110 km/h. It has also been politically discussed whether some highways should have a speed limit of 130 km/h. Increasing the speed limit on highways with considerable traffic volumes will also increase the requirements for the road maintenance during wintertime, when the driving conditions will be extensively changed during periods with snow and ice on the road surface. Hence, one should expect periods where there is a need to activate relevant ITS applications informing the travellers on the driving conditions and the reduced speed limit.

This report investigates how countries with similar winter conditions as Norway have implemented relevant ITS applications for informing travellers about the dangerous driving conditions and the reduced speed limit. The report also describes the status of Norwegian regulations and guidelines enabling the implementation of variable speed limits in Norway. Finally the report describes a more detailed study of data collected on a highway section of E18 in the south eastern part of Norway and a proposal for a relationship between the estimated friction and the recommended speed limit.

The report describes the different types of weather and road information systems in Finland, Denmark, Sweden, Iceland, Austria, Germany, Canada and USA. The physical architecture is described as well as the functional architecture, the roles and responsibilities and objectives and evaluations. The review shows that all the countries have these types of systems but there are differences concerning what type of information that is collected and distributed to the users. There are also differences in the different channels used, e.g. three of the systems are distributing the information both via web interface and smartphone application interface while others only have the web interface. Six of the systems reviewed used variable speed limit (VSL) messages but the implementation of VSL was very often limited to specific road sections, corridors, regions or states.

One of the main objectives was to focus on VSL systems used by Traffic Management Centres (TMC) when changes in speed limits is based on information received about real time local weather and road conditions. The Variable Speed Limits are implemented in many countries, mainly to increase the traffic efficiency and to reduce the risk of road accidents. These systems rely on data about traffic volume and speed, as well as information on current road works. However in countries where the weather and road conditions are similar to those in Norway, the systems are also used to inform drivers that the speed limit has temporarily been reduced. These systems are currently often associated with other road signs and messages to give more information about slippery roads and poor visibility conditions. Even if the effect on the number of accidents was difficult to quantify in some studies due to limited data and the side effects of other factors, several studies showed a positive impact on traffic safety and on the reduction of the average speed of the vehicles. Reduced travel times, decreased fuel consumption and lower emissions were also cited as benefits of the VSL system. The success of an effective weather control system was reported based on an efficient recognition of hazardous weather and road conditions, use of variable slippery road signs to support the variable speed limit system and moderately use of the highest speed limits.

The implementation of variable speed limits due to weather and road surface condition is not yet authorised by the Norwegian guidelines on variable traffic signs. The guidelines states the following:

Reduction of the speed limit due to difficult weather or driving condition shall not take place. Strong wind is the only exception. Automatic weather and road surface condition measurements and speed limit control criteria are so far not reliable enough to be used in variable speed limit system.

The Norwegian Public Roads Administration has worked with implementing variable speed limits and new guidelines for the use of variable speed limits. Variable speed limits due to weather and road surface condition has been one of the issues that have been raised in this work but there are no guidelines so far (Oct 2016) describing if and when variable speed limits could be used.

A more detailed study was carried through for data collected at 5 weather stations along E18 in Vestfold County in southern Norway. Altogether more than 80.000 records with weather and road surface condition were collected during wintertime in 2015 and 2016. The availability of the information collected was 96.3 % as an average for the data collected during January – March 2016. By availability is meant that there is a complete record received from the weather station every 10 minute and all requested parameters have a realistic value. The study of all available records showed that the percentage of friction values below 0.6 varied from 2.9 % to 5.7 % for the 5 stations during winter 2016. The friction values below 0.2 varied from 1.1 % to 2.1 % for the same 5 stations.

An even more detailed study was performed for the period between Jan 7 to Jan 14, 2016. The driving conditions were quite challenging during this period with several snowfalls and very slippery roads. The data from the 5 stations were analysed and there was a good correlation between the friction estimated by the remote friction sensors and the measured thickness of snow, water and ice on the road surface which was as expected. It was also found a correlation between the friction estimated by the sensors and the speed selected by the drivers.

The report also includes a proposal for variable speed limits based on the estimated friction. The permissible maximum speed is decreased in steps of 10 km/h from 110 down to 70 km/h depending on the friction starting on friction below 0.6. It is important that the speed limits that are used for controlling the traffic during reduced, poor and dangerous road conditions are accepted by a majority (85 % fractile) of the drivers avoiding too many speed violators and loss of respect for traffic signs and control.

The authors of the report recommend that the Norwegian Public Roads Administration continues its work in further development of the existing weather and road condition information systems. First of all, it is important to simplify the user interface facilitating one access point for the user by an integration of the different sources and systems. The specification, design and implementation of such systems should be based on international standards and best practice as described by the Nordic road authorities having already implemented this type of systems.

The authors also recommend that the Norwegian Public Roads Administration starts the process of developing a Norwegian guideline for the implementation of variable speed limits (VSL) on motorways with high speeds in line with the best practice and recommendations as described by the EasyWay project taking into account the data collected and analysed at E18 in Vestfold. Further it should remove the existing barriers in the existing guidelines on variable message signs that prevents the implementation of VSL based on road and weather conditions. Finally, the quality of the sensors should be investigated ensuring reliable data for an automatic control of variable speed limits.

Sammendrag

Byggingen av motorveier med høy fart og store trafikkvolumer øker i Norge. Fartsgrenser er tilsvarende økt fra 90 og 100 km/t opp til 110 km/t. Det har også vært politisk diskutert om enkelte motorveier skal ha en fartsgrense på 130 km/t. En øking av fartsgrensen på motorveier med betydelige trafikkmengder vil også øke kravene til vegvedlikehold om vinteren når kjøreforholdene blir vesentlig endret i perioder med snø og is på kjørebanen. Derfor bør man forvente perioder hvor det er behov for å ta i bruk relevante ITS tjenester for å informere de reisende om kjøreforhold og redusert fartsgrense.

Denne rapporten undersøker hvordan land med tilsvarende vinterforhold som Norge har implementert relevante ITS tjenester for å informere de reisende om farlige føreforhold og midlertidig nedsatte fartsgrenser. Rapporten beskriver også status på norske retningslinjer som muliggjør innføring av variable fartsgrenser i Norge. Rapporten beskriver også en mer detaljert studie av data samlet inn fra 5 værstasjoner langs en strekning av E18 i Vestfold. Basert på denne studien er det også utarbeidet et forslag til forholdet mellom estimert friksjon og anbefalt hastighet (midlertidig nedsatt fartsgrense).

Rapporten beskriver de ulike typene av systemer for måling og melding av vær og vegstatus i Finland, Danmark, Sverige, Island, Østerrike, Tyskland, Canada og USA. Den fysiske og funksjonelle arkitekturen er beskrevet i tillegg til roller og ansvarsfordeling, mål og eventuelle evalueringer av systemene. Gjennomgangen av litteratur viser at alle disse landene har systemer for veg- og vegstatusinformasjon, men det er forskjeller når det gjelder hvilken type informasjon som er samlet inn, behandlet og distribuert til brukerne av informasjonen. Det brukes også litt forskjellige informasjonskanaler. F.eks. sender tre av systemene ut informasjon både via web og smarttelefon app, mens andre bare har et webgrensesnitt. Seks av de systemene som ble studert brukte variable fartsgrenser, men bruken av slike variable fartsgrenser var ofte begrenset til spesielle motorvegseksjoner, vegkorridorer, regioner eller stater.

Et av hovedmålene i prosjektet var å fokusere på hvordan variable fartsgrenser ble brukt av trafikkstyringssentraler i de tilfellene det var sanntidsinformasjon om vær og vegstatus som var årsak til reduserte fartsgrenser. Variable fartsgrenser er implementert i mange land, men hovedsakelig for å øke effektiviteten i trafikkavviklingen og for å redusere risikoen for ulykker. Disse systemene bygger stort sett på informasjon om trafikkvolum og hastighet og informasjon om vegarbeider.

I land med tilsvarende vær og føreforhold som i Norge brukes også slike systemer til midlertidig nedsettelse av farten. Den nedsatte farten er ofte supplert med andre skilt og meldinger som gir litt mer informasjon om de glatte kjøreforholdene og eventuelt dårlige siktforhold. Flere studier viste en positiv effekt på trafikksikkerheten og reduksjon av gjennomsnittshastigheten til kjøretøyene selv om antall ulykker var lite og selv om det var vanskelig å isolere effekten av bare de variable fartsgrensene. Redusert reisetid, redusert drivstofforbruk og mindre utslipp ble også funnet som positive effekter av systemer som brukte variable hastigheter. Suksessen for et effektivt styringssystem basert på vær- og føreforhold ble knyttet til en effektiv registrering av vær- og føreforhold, bruk av variable skilt som viste glatt kjørebane og moderat bruk av de høyeste hastighetene.

Innføringen av variable fartsgrenser basert på vær- og føreforhold er foreløpig ikke hjemlet i norske retningslinjer for variable skilt. Retningslinjene (Statens vegvesen Håndbok V321 Variable skilt sier følgende om bruk av variable fartsgrenser:

Nedskilting av fart gjøres ikke pga. vanskelige vær- og kjøreforhold. Unntaket er ved sterk vind. Automatiske vær-/føremålinger og styringskriterier er foreløpig ikke tilstrekkelig sikre for å kunne benyttes i et

variabelt fartsgrensesystem.

Statens vegvesen har arbeidet med innføring av variable fartsgrenser og nye retningslinjer for bruk av variable fartsgrenser. Bruk av variable fartsgrenser ved dårlige vær- og føreforhold har vært en av sakene som har vært oppe til diskusjon, men foreløpig (oktober 2016) er det ikke noen norske retningslinjer som sier noe om i hvilke tilfeller det kan brukes og hvilke fartsgrenser som skal benyttes,

Det ble gjennomført en mer detaljert studie av data samlet inn fra 5 værstasjoner langs E18 i Vestfold. Mer enn 80.000 datarecords med vær- og føreforhold ble samlet inn under vintersesongene 2015 og 2016. Tilgjengeligheten på data var i gjennomsnitt på 96,3 % i perioden januar – mars 2016. Med tilgjengelighet menes at det er mottatt en komplett record fra værstasjonene hvert 10 minutt og at alle etterspurte parametere har en realistisk verdi, f.eks. friksjon ikke lik 0. Studien av alle tilgjengelige records viste at andelen friksjonsverdier under 0,6 varierte mellom 2,9 % og 5,7 % for de 5 værstasjonene vinteren 2016. Friksjonsverdiene under 0,2 varierte mellom 1,1 % og 2,1 % for de fem målestasjonene.

Det ble også gjennomført en enda mer detaljert studie for perioden mellom 7 og 14. januar 2016. Kjøreforholdene var meget vanskelig i denne perioden med flere snøfall og glatte veger. Data fra de fem stasjonene ble analysert og det ble som forventet funnet en god sammenheng mellom de estimerte friksjonene og de målte verdiene for snø, vann og is på vegoverflaten. Det ble også funnet en sammenheng mellom friksjonen målt av friksjonssensorene og den hastigheten som ble valgt av bilførerne.

Rapporten inneholder også et forslag til variable hastigheter basert på målte friksjonsverdier. Den tillatte hastigheten er redusert i trinn på 10 km/t fra 110 km/t ned til 70 km/t avhengig av den målte friksjonen. Nedtrappingen starter når friksjonen er målt til mindre enn 0,6. Det er viktig at den hastigheten som blir valgt for å kontrollere trafikken under reduserte, dårlige og farlige vær- og føreforhold blir akseptert av minst 85 % av bilførerne slik at en unngår for mange fartsovertredelser og redusert respekt for skiltede fartsgrenser.

Rapporten anbefaler at Statens vegvesen fortsetter sitt arbeid med videre utvikling av eksisterende informasjonssystemer for vær- og føreforhold. Først og fremst er det viktig å forenkle brukergrensesnittet slik at brukeren har kun ett kontaktpunkt, f.eks. ett webgrensesnitt, for alle de ulike informasjonssystemene som finnes i dag. Spesifikasjonen, designet og implementeringen av et slikt system bør baseres på internasjonale standarder og beste praksis slik det er beskrevet av de nordiske vegmyndighetene som allerede har innført slike systemer.

Rapporten anbefaler også at Statens vegvesen starter prosessen med å utvikle retningslinjer for bruk av variable hastigheter på høyhastighetsveier i de situasjonene hvor vær- og føreforhold tilsier at fartsgrensen bør reduseres. Disse retningslinjene bør bygge på internasjonale standarder og beste praksis og anbefalinger slik de er beskrevet i EasyWay-prosjektet samtidig som en tar i betraktning de dataene som er samlet inn på E18 i Vestfold. Videre bør Statens vegvesen starte arbeidet med å fjerne de barrierene i dagens håndbok om variable skilt som hindrer innføringen av variable hastighetsgrenser basert på vær- og føreforhold. Det anbefales også at kvaliteten på sensorene undersøkes nærmere slik at en får sikre data for en mer automatisering av variable fartsgrenser.

1 Introduction

The construction of highways with high speeds and traffic volumes increases in Norway. Speed limits are consequently increased from 90 and 100 km/h, up to 110 km/h. It has also been politically discussed whether some highways should have a speed limit of 130 km/h.

Source: dinside.no

Figure 1 Norwegian motorway with speed limit 110 km/h

Increasing the speed limit on highways with considerable traffic volumes will also increase the requirements for the road maintenance during wintertime, when the driving conditions will be extensively changed during periods with snow and ice on the road surface. Hence, one should expect periods where there is a need to activate relevant ITS applications informing the travellers on the driving conditions and the reduced speed limit.

Highways with high traffic volume have winter maintenance requirements specifying the road surface to be visible (black asphalt) in a rather short time after the snow fall (Maintenance Class A-standard (DkA)). The road surface should always be without snow or ice (wet or dry). However, there are certain weather conditions that prevent the road operator to maintain the required level of maintenance class A. During these periods there is a need to inform travellers that the driving conditions are not as they usually are and it may even include a temporary reduction of the speed limit until the required maintenance level has been achieved again.

A reduction of the stopping distance and the vehicle braking and steering abilities during winter time when the required level of maintenance cannot be achieved, is critical on highways with high traffic volume and speeds. During other seasons, heavy rain and dense fog meet some of the same accidental risks and also imply a need for a reduced speed limit. Research has shown that drivers reduce the speed when the driving conditions are getting worse but not to the extent that is needed for keeping the risks on an "acceptable" level. The consequence is an increased probability for that severe traffic accidents will occur during these periods when drivers do not adapt their speed to the dangerous driving conditions. This may have fatal consequences for those who are directly involved in the accident and major delays for the other road users that are implicitly involved.

This report investigates how countries with similar winter conditions as Norway have implemented relevant ITS applications for informing travellers about the dangerous driving conditions and the reduced speed limit. The report also describes the status of Norwegian regulations and guidelines enabling the implementation of variable speed limits in Norway.

Finally the report describes a more detailed study of data collected on a highway section of E18 in the south eastern part of Norway.

The status in Norway (2016) concerning road and weather information systems and variable speed limits is shortly described below.

Road users may easily access the web cameras installed along the main road network in Norway. The cameras are installed at critical points where road and weather conditions may cause problems for the road users, e.g. at mountain passes during winter time. However, the pictures from the web cameras are also used for studying traffic conditions in the road network in the larger cities all around the year.

The pictures below in Figure 2 show some of the user interface pictures collected from www.vegvesen.no/trafikkinformasjon/Reiseinformasjon/Trafikkmeldinger/Webkamera. The picture to the left shows the cameras in the mountain area called Dovre in the middle region of Norway and the picture to the right shows the actual picture from one of the three cameras behind the orange circle marked with the number 3 (three cameras).

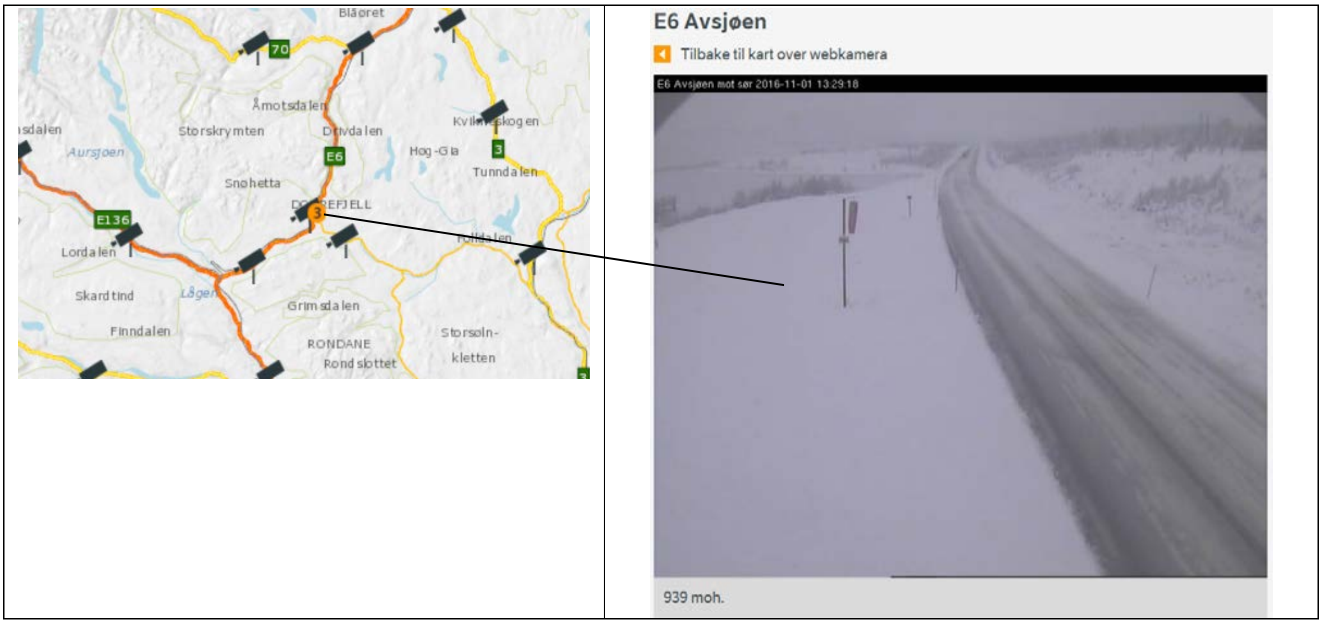


Figure 2 Road and weather information cameras available for road users

The road user may also access road and weather information by the link www.vegvesen.no/trafikkbeta which is a Beta version of a future road and weather information system. An example on road and weather condition is shown in Figure 3 (so far in Norwegian only).

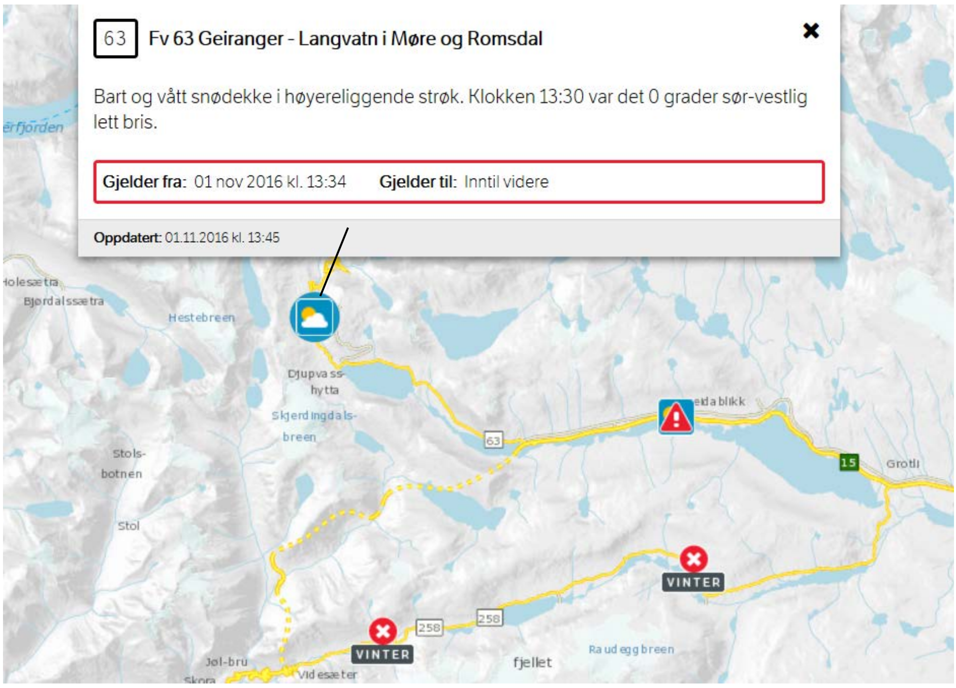


Figure 3 Example on Road and weather information for road users

The road users may also access road and weather information by the link www.vegvesen.no/trafikkinformasjon/Reiseinformasjon/Trafikkmeldinger. The information is in clear text without any graphics. Figure 4 shows an example on the text message. The example describes the conditions for the road section shown in Figure 2. The conditions are described as: 'Road surface covered with snow and there are possibly sections with slippery road. Further, at 05:45 it was -3 °C, light breeze and snowing. The information is valid from 01.11.2016 06:00 until further information is given'. Hence, by combining the information from the web cameras with the more detailed text information it is possible for the road user to have a road and weather information that could support him/her in taking the right decisions on whether to go or not, to postpone the travel or to be better prepared for the bad road and weather conditions. A more user friendly interface would of course be that the camera and the text was combined in the same web page as it is done in for instance the Finnish web interface for road users.

Ev 6 Dovrefjell (Dombås bom - Grønnbakken bom)

Ev 6 — **Dombås bom - Grønnbakken bom, på strekningen Dovrefjell**

Oppland, Sør-Trøndelag

Snødekke, fare for glatte partier. Klokken 05:45 var det -3 grader, lett bris og snø.

Gjelder fra: 01.11.16 kl. 06:00 Gjelder til: Inntil videre

Figure 4 Example on Road and weather information for road users

There is also a road weather application for the road operators and contractors undertaking the winter road maintenance. The application is called Vegvær (Road weather) and a beta version is available on www.vegevsen.no/trafikkbeta. The application is based on road and weather information from 280 weather stations. Some of the stations have also sensors for snow avalanches. The application collects information from the 280 stations and the information is forwarded to the Norwegian Meteorological Institute that performs a quality assurance of the collected data. The data are both presented as they are and used in a prognosis model for the road surface conditions. This information is again made available for the road operators and the contractors that are contracted for snow removal, salting and sanding. The prognosis for the road surface temperature and road surface condition, e.g. covered with snow, ice, dry etc., are updated each hour and the prognosis are presented for the next 10 hours [35].

Source: Stine Mikalsen

Figure 5 One of the 280 weather stations

Variable speed limits due to road and weather conditions are not implemented on Norwegian roads (2016). This report will be part of the preparation work for such implementations and is a basis for further investigation and research.

2 Objectives

The objectives of this report are the following:

- Describe state-of-the-art for:
    - ITS applications informing travellers about weather and road conditions that may cause an increased risk level concerning traffic safety
    - ITS applications that reduce the speed limit due to bad weather and road conditions
- Describe potential legal and/or regulation barriers that may become a barrier for the introduction of variable speed limits in Norway
- Describe how an ITS application for variable speed limit based on collected road and weather information data on E18 in Vestfold (2 + 2 lanes highway), Norway, may function
- Recommend future work based on the findings of the previous objectives

3 Methodology

3.1 ITS applications studied

The objective of this report is to focus on these two following ITS applications:

1. To inform travellers about weather and road conditions

This application includes:

- monitoring the road and weather conditions by data collection
- management of data collected
- distribution of road and weather condition information to the travellers

Picture source: ntl.bts.gov

2. To reduce the speed limit due to weather and road conditions

This application includes:

- monitoring the road and weather conditions by data collection
- management of data collected
- effectuate reduced speed limits

Picture source: thetimes.co.uk

The state-of-the-art methodology applied to collect relevant information about these two ITS applications is described below:

- Define the physical architecture for systems that:
  - Collects data about weather and road conditions
  - Determine the status for now and for the next coming hours (prognoses)
  - Informs the travellers about the weather and road conditions
  - Effectuates (manually or automatically) traffic management measures like reduced speed limits
- Define the functional architecture for this type of systems
- Define the role and responsibility model
- Describe existing systems having implemented one or both of these ITS applications
- Describe the experiences achieved by the ITS applications in operation
- Describe the findings from relevant research and scientific articles

3.2 The physical architecture

The Physical architecture is based on the reference model developed by ISO TC 204 ITS as defined in ISO 21217 ITS – Communication access for Land mobile – Architecture. The reference model for Information and Communication Technology (ICT) systems in Intelligent Transport Systems is built on 4 sub-systems as shown in Figure 6.

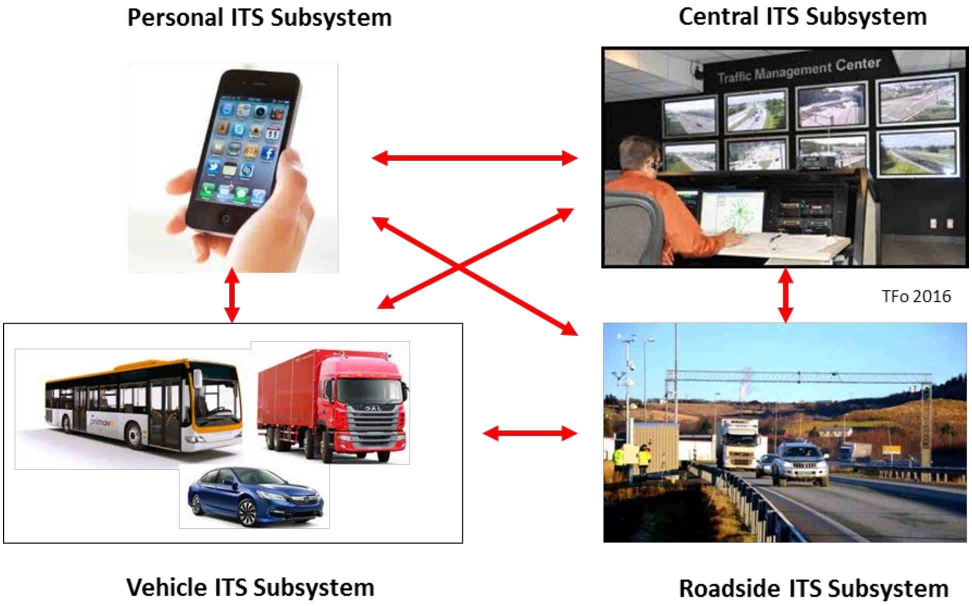


Figure 6 The 4 ITS sub-systems

Each sub-system is built on the same internal architecture and consists of an ITS station that hosts the ITS application(s), communication devices (e.g. routers), gateways to peripheral equipment and the peripheral equipment, e.g. roadside sensors, vehicle sensors and traffic signs and signals. The internal communication in a sub-system is not defined in the standards but the communication between the ITS stations in different sub-systems has been defined in other ISO and ETSI standards not referenced here.

The following sub-systems are defined in ISO 21217:

- Personal ITS sub-system; implemented in hand-held devices (Figure 7). The personal ITS sub-system provides the application and communication functionality of ITS in hand-held devices, such as PDAs, mobile phones, etc. It shall contain a personal ITS station. The device used as a personal ITS station may also perform HMI functionality as part of another ITS sub-system, connecting to this via the ITS station-internal network.

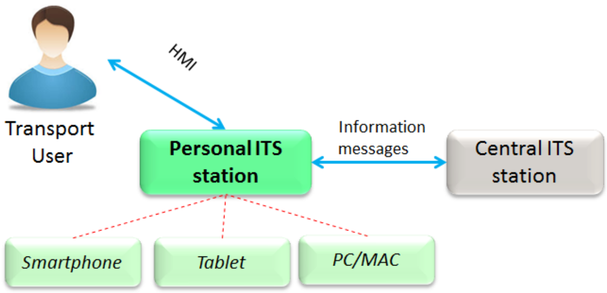


Figure 7 The Personal ITS sub-systems

- Vehicle ITS sub-system; implemented in cars, trucks, etc., in motion or parked (Figure 8). The vehicle ITS sub-system shall contain a vehicle ITS station and may contain ITS-S interceptors. The ITS-S interceptors in the vehicle ITS sub-system are typically a vehicle ITS-S gateway and an ITS-S router. The vehicle ITS-S gateway provides functionality to connect the components at the proprietary vehicle network, e.g. electronic controller units (ECUs).

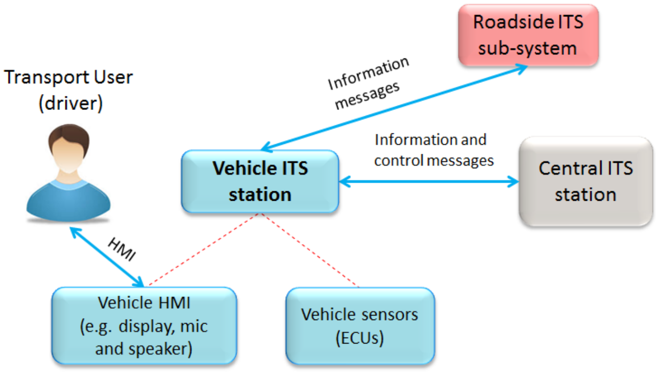


Figure 8 The Personal ITS sub-systems

- Central ITS sub-system; part of an ITS central system (Figure 9). The central ITS sub-system shall contain a central ITS station and may contain ITS-S interceptors. The ITS-S interceptors in the central ITS sub-system are typically a central ITS-S gateway and an ITS-S border router.

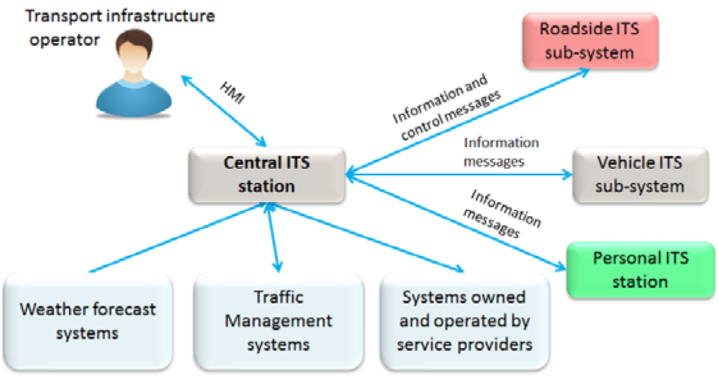


Figure 9 The Central ITS sub-systems

- Roadside ITS sub-system; installed on gantries, poles, etc (Figure 10). The Roadside ITS Sub-system consists of the Roadside ITS station with the ITS applications and the peripheral roadside equipment connected to the Roadside ITS station (ITS-S). The roadside equipment is most often traffic signals and signs and different types of sensors, e.g. Weigh-in-motion (WIM) sensors, digital cameras, weather and environmental condition sensors and volume and speed sensors. The Roadside ITS-S communicates with the Vehicle, Personal and Central ITS stations.

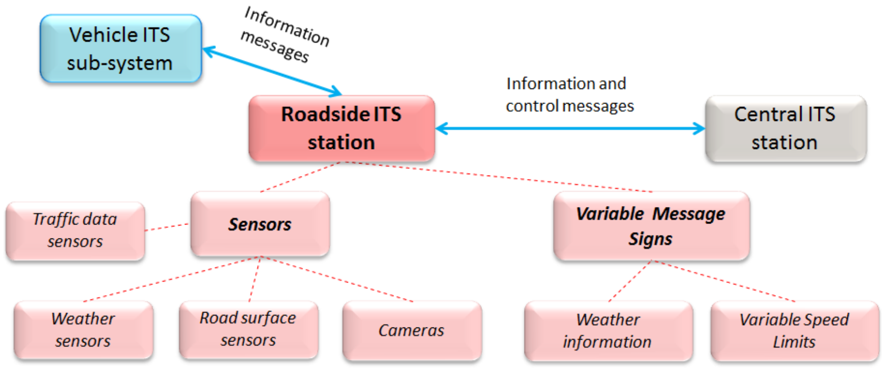


Figure 10 The Roadside ITS sub-systems

3.3 A functional architecture

Figure 11 shows the overall functional architecture that will be used for the description of the existing systems. The description will focus on how the weather and road conditions information is collected, how the decision on information distribution is taken, how the decision on speed limit reduction is taken and how the weather and road condition information is distributed to the Transport users (travellers).

The decision on the distribution of information of weather and road conditions has the outcomes Yes or No. In some cases the road operator decides to show the information even if the collected data are not above the defined limits. Hence, there are two alternative processes for the No outcome.

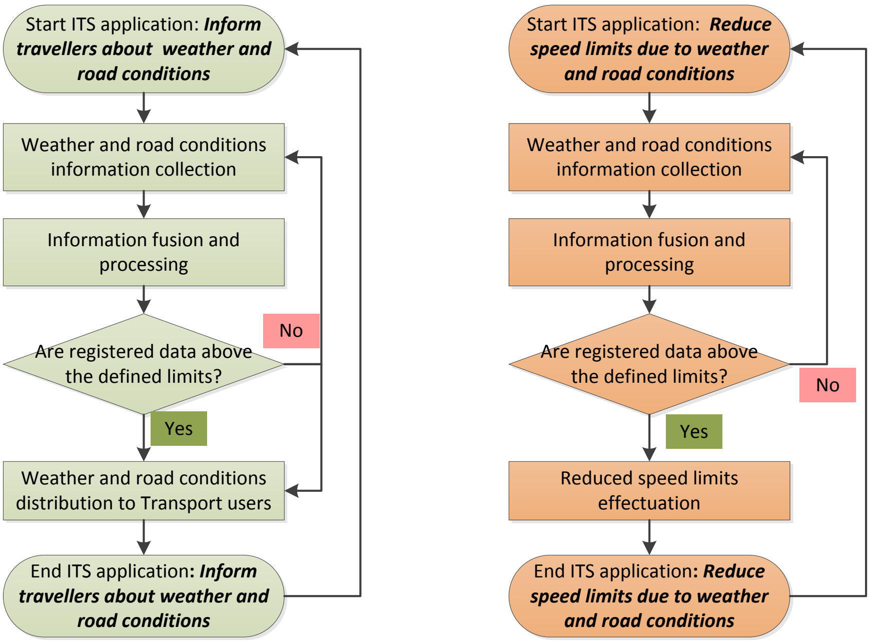


Figure 11 The overall functional architectures

3.4 A role and responsibilities model

Several roles will be involved in the daily operation of the two ITS applications. The description of the systems in the different countries will focus on the roles called the Road network operator and the Traffic manager. However, five roles are described below to have a complete picture of the major roles involved.

The *Road network operator* is responsible for the daily operation of the physical road network, e.g. road maintenance, and the equipment related to the road network, e.g. the Roadside ITS stations. The Norwegian Public Roads Administration (NPRA) will be the Road network operator for the main roads in Norway. The responsibilities of the Road network operator will always be related to the NPRA but the NPRA may outsource and/or delegate the tasks being part of the responsibilities to other service providers, e.g. private *Contractors* that provides maintenance services as clearing the road of snow and salting.

The *Traffic Manager* is responsible for the best possible traffic flow during normal and abnormal traffic situations through efficient traffic management and incident handling. He is also responsible for the provision of the traffic situation and supporting facilities and services, e.g. route guidance. The main responsibilities will be:

- monitoring and controlling the traffic flow or individual vehicles by guidance or orders given to traffic flows or individual vehicles
- management of road and traffic status information and provisions of such information.

The *Transport user* requests and uses information about the weather and road conditions provided by the *Traffic Manager*. The Transport user is also obliged to adhere to the control messages, e.g. reduced speed limits effectuated by the *Traffic Manager*. The Transport User may also be called the *ITS application User*.

An actor providing maintenance services will both be a Contractor and a Transport User as he uses the information provided by the Traffic Manager.

Service Providers are roles that provide different types of services to the *Road Network Operator* and the *Traffic Manager*. Some examples of services are Information and Communication Technology (ICT) services, e.g. GSM/GPRS, travel information services through different kinds of media, e.g. radio and SMS, weather forecast providers, positioning systems operators, e.g. GPS and ITS application service providers, e.g. ITS apps for smartphones and tablets.

Contractor is a role taken by many private and semi-public companies providing maintenance services, e.g. clearing of snow and salting. The Contractors provide their services to the Road Network Operator who is responsible for the physical road network including planning, building and maintenance. The actor taking the role as a Contractor will also be a Transport User in those cases where the actor requests information from the Traffic Manager about weather and road conditions. In some cases the Transport User has also requested a Push information activity from the Traffic Manager, i.e. the Transport User is automatically updated on specific changes in the weather and road conditions.

The main relationships between the different roles are shown in Figure 12.

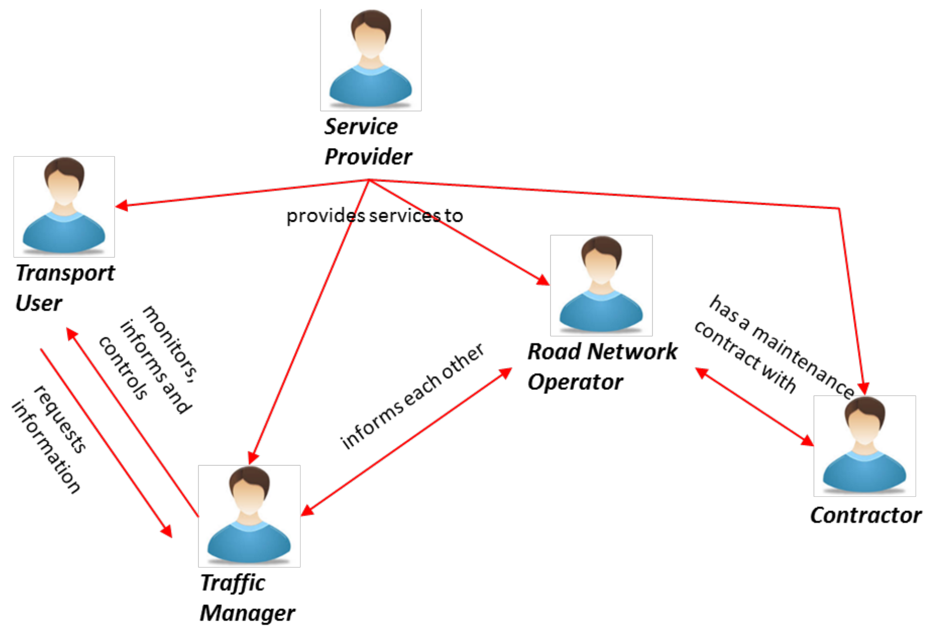


Figure 12 The main relationships between the roles

4 Road Weather Information Systems (RWIS) definitions and components

The European standard on RWIS [18] defines the RWIS concept for public roads and traffic surfaces. The standard applies to the acquisition of data on weather-related road and environment conditions as well as their forecast.

A RWIS is in [18] defined as a combination of technologies that uses historic and current climatological data to develop road and weather information to support road traffic related decisions.

The three main elements are:

- Environmental sensor tools (fixed or mobile) to collect data
- Models and other advanced processing systems to develop forecasts and tailor the information into an easily understood format
- Dissemination platforms on which to display the tailored information

Figure 13 shows the components defined in [18]. Some of these components are found in the physical architecture described in 3.2, e.g. road weather stations are ITS Roadside sub-system and Mobile Data Acquisition could be the Vehicle ITS sub-system and Man Machine Interface could be the Personal ITS station, e.g. a smartphone with an RWIS app.

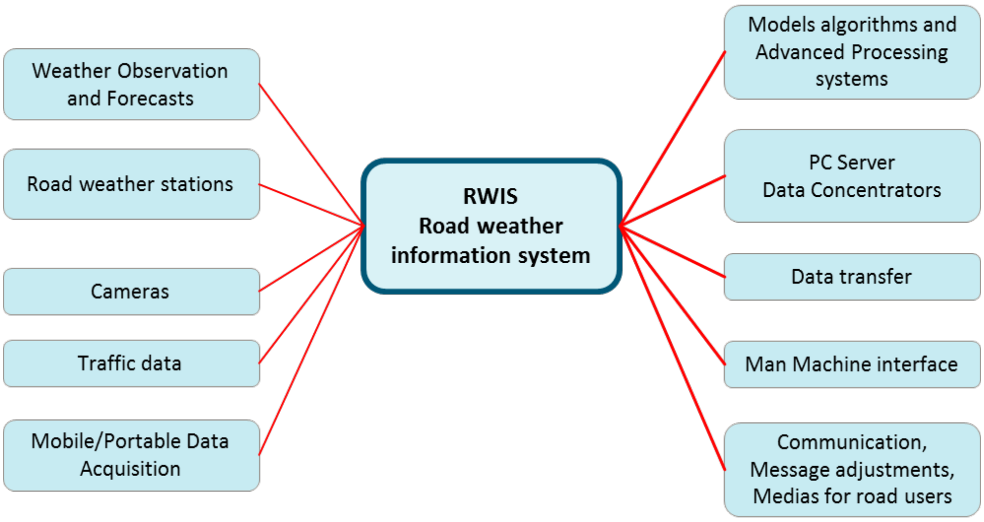


Figure 13 The RWIS components defined in [18]

Weather observation and forecast covers either raw data presented by for instance meteorological institutes or processed data provided by a service provider which could be a met institute or a commercial partner.

Road weather stations are the components that provide the environmental data related to the weather, e.g. air temperature and precipitation. Other environmental data are related to the road itself, e.g. road surface temperature and surface condition, e.g. wet/dry/frozen/salted.

Cameras provides pictures that can be manually or automatically processed, e.g. to register snow and ice on the road surface as well as de-icing processes.

Traffic data providing data on volume, typology and characteristics could be taken into account for the analysis of the RWIS data.

Mobile or portable data acquisition systems monitor atmospheric parameters and road conditions at a given time and position, for example at the time and position of the mobile unit.

Models algorithms and Advanced Processing systems aggregate and process data from different sources according to the specifications of the final user (road managers, forecasts and road users).

PC, Servers and Data Concentrators allow locally and centrally the collection, storage, processing and distribution of the data. To collect and distribute the information, several communication channels can be used such as the Internet, Intranet, satellite, dial-up lines, etc.

Data transfer use different communication channels (phone lines, radio signals, etc.).

Man Machine interface consists of visualisation and operation tools, adapted to the user needs.

Communication, Message adjustments, Medias for road users: Information can be transmitted to other systems like VMS, on-board navigation systems, etc.

5 State-of-the-art for weather and road condition information systems

5.1 Introduction

This section describes a summary of the findings in USA, Canada and 6 countries in Europe that have road and weather conditions that are comparable with the different road and weather conditions in Norway when focusing on the winter period. The description follows the methodology described in 3.1 and for each system/country the following subjects are described:

- The information sources, i.e. references that have been used.
- The physical architecture of the system
- The functional architecture
- The actors involved and the roles or parts of roles they are fulfilling
- The main objectives for implementing the ITS application and any evaluation of the impacts

The descriptions of the national RWIS systems are found in the Annex A – H:

- Annex A: Finland on page 60
- Annex B: Denmark on page 64
- Annex C: Sweden on page 67
- Annex D: Iceland on page 71
- Annex E: Austria on page 75
- Annex F: Germany on page 81
- Annex G: Canada on page 86
- Annex H: United States on page 91

5.2 Summary of some of the findings

The Table 1 shows some of the findings from the state-of-the-art study. The information given in the last column is based on the information available at the Road authorities home pages and other relevant publications found in literature review. There might be new information related to the use of variable speed limits based on weather and road conditions that are not yet published (Oct 2016).*We have also noted that several of the applications described in the Annexes A – H are subject to dynamic changes and new versions since the project and information collection started.*

The last column shows whether weather based Variable speed limits (VLS) have been implemented. A Yes does not mean that the VLS systems have been implemented on a national level. Very often the VLS implementation is limited to one or more specific motorway or highway corridors within a region or state.

Table 1 : Summary of findings in the state-of-art study

Country	Road user information interfaces	Weather-related information given in the road user web interface	Other users of road weather information	Use of variable speed limits based on weather and road conditions
Finland	www.liikennetilanne.liikennevirasto.fi/ *NB! It should be noted that Finland has a winter based reduction of motorway speed limits. The speed limits drops from 120 km/h to 100 km/h during winter.*	Road condition (three categories), picture of road and driving conditions (roadside camera)	Dedicated weather service for winter maintenance contractors	Yes
Denmark	www.vejdirektoratet.dk/DA/trafik/ vintertrafik/Sider/Default.aspx Also available on mobile phone app: Vintertrafik	Slippery road, salting, traffic messages, pictures (web cameras), temperature and wind. Information is only given during winter time.	Traffic Information Centres and winter maintenance contractors	No
Sweden	www.trafikinfo.trafikverket.se/LIT/ #url=Vagtrafiken/Karta	Middle and max wind, precipitation, air temperature, possible difficult driving conditions, road surface with snow and/or ice. Web cameras showing road surface.	From the available literature there were no indications that the maintenance contractors or other service providers were offered dedicated information services	Yes
Iceland	www.road.is	Spots of ice, slippery, extremely slippery, wet snow/snow, difficult driving, storm conditions, snowfall, blowing snow, blizzard, snow showers, fog, temperature, wind speed and direction. Web cameras showing road surface	From the available literature there were no indications that the maintenance contractors or other service providers were offered dedicated information services	No

Country	Road user information interfaces	Weather-related information given in the road user web interface	Other users of road weather information	Use of variable speed limits based on weather and road conditions
Austria	www.asfinag.at and smartphone app: Unterwegs	Information on mandatory use of snow chains. Web cameras showing weather, road and traffic conditions	The road and weather information systems has a direct connection to the maintenance vehicles both collecting and offering information	Yes
Germany	www.dwd.de/swis and smartphone app: DWD Warnwetter	Map with weather conditions for Germany. Specific warnings are given, e.g. Severe weather is shown by red colour on the map. In addition there could be warnings about snow, ice and slippery roads. No links to web cameras.	A more detailed information service is available for DWD customers.	Yes
Canada	Example: www.ontario.ca/511 Each province has its own system	Map with weather related road condition: Bare, Partly covered and Covered (with snow and/or ice). There are also links to weather cameras showing road conditions.	Dedicated weather service for winter maintenance contractors (status and prognoses)	Yes
USA	www.fhwa.dot.gov/trafficinfo/	Maps with a rather detailed set of different road and weather conditions. Links to web cameras with information on air temperature, road surface temperature, wind direction and speed, humidity.	Dedicated weather service for winter maintenance contractors	Yes

6 State-of-the-art for Variable speed limits (VSL)

6.1 Introduction

One of the main objectives was to focus on VSL systems used by Traffic Management Centres (TMC) when changes in speed limits is based on information received about real time local weather and road conditions.

The Variable Speed Limits are implemented in many countries, mainly to increase the traffic efficiency and to reduce the risk of road accidents. These systems rely on data about traffic volume and speed, as well as information on current road works. However in countries where the weather and road conditions are similar to those in Norway, the systems are also used to inform drivers that the speed limit has temporarily been reduced. These systems are currently often associated with other road signs and messages to give more information about slippery roads and poor visibility conditions.

An informative state-of-the-art report about VSLS should include a good overview about:

- The technical solutions used to collect real time data about the road and weather conditions,
- The data processing and models used to produce meaningful information to the TMC,
- The control strategy and principles used by TM operators for making decisions about the speed limit to be set,

Our main objective was to collect as much information as possible about VSL systems in use in TMCs, their degree of automation, and details about the control principles in place to operate the VSL systems on roads in relation to road and environmental conditions.

However the literature search shows that:

- Most published scientific articles are mainly concerned with the use of microscopic traffic simulations to evaluate future implementations of VSL System. They also propose new control strategies and evaluate safety and environmental impacts.
- Most of the public Traffic management documents available on the Internet deal with temporary variable signs implemented on roads in the case of road works.
- Most of the evaluation reports about the use of VSLS are written in the national languages.
- There is no or very little information on the strategies and procedures behind the use of VSL. An exception is the Finnish literature available in English that have some information at least on the conditions for reducing the speed due to road surface conditions, heavy rain or poor visibility.

6.2 Current status about VSL

6.2.1 Harmonisation

The Easy Way projects [19] and its Viking Evaluation Group [20] have produced relevant reports for harmonisation and standardisation of traffic management services. These project activities are based on the collaboration between several countries. They provide several evaluation results and lessons learnt for transferability purposes, including the use of VSL systems. The report produced by the Finnish Transport Agency in 2004 [21] regrouped practices and deployments of Variable Message Signs (VMS) and included variable speed limits in the Viking countries including Denmark, Finland, Germany, Sweden and Norway.

Short term issues and actions for harmonisation have been identified:

- Light-emitting signs with inverted colours are recommended because they are better recalled and more effective than electromechanical signs. There are differences between countries about the appearance of the variable signs and whether they should differ from the fixed signs.
- The use of flashing lamps on speed limit signs has to be used with precaution as it can confuse drivers.
- In case of message absence situation, a black sign (LED) or the last message is shown. If the sign is out of order, the system is set manually.
- In Finland, Germany and Norway the system is used temporarily during road works.
- The location of the speed limit signs can differ between countries. For example, in Germany VSL signs are used on specific lanes on motorways.
- The control of VSL is based on weather and road condition data in most of the VIKING countries.
- The different road and weather data processed to control the VSLs are provided by sensors and cameras:
    - Surface state sensors (e.g. non-intrusive technology providing conditions such as surface state, thickness of moisture, road friction)
    - Weather detector (e.g. visibility, precipitation, road temperature)
    - Road embedded sensors
    - Radar and satellite images
    - Road and weather forecast model
    - Road weather cameras
    - Floating Car Data
- The levels of automation vary nationally and between the countries. The system is often based both on manual and automatic control of the VSL signs. The control system relies on the automatic categorisation of road and weather conditions, defined principles and criteria for decision making concerning the choice of speed limits.

The **long term harmonisation** need identified was to develop a higher level of automation to be able to respond as fast as possible in case of sudden changes in weather and road conditions and to identify a more standardized set of control principles.

6.3 Examples on weather based VSL

6.3.1 Finland

Figure 14 shows an example on the current conditions parameters for classifying the road conditions as dangerous (D) in Finland. The example is collected from [23]. The figure also shows that the speed will automatically be reduced from 120 or 100 km/h down to 80 km/h when the road conditions (road surface condition, rain or visibility) are classified as (D). The speed may also be reduced to 60 km/h manually if the traffic management operators find it necessary.

PARAMETERS	VALUES	VMS-SIGN	INFO SIGN
(D) DANGEROUS ROAD CONDITIONS Speed limit by automatic system 80 km/h Speed limit 60 km/h manually, if traffic control center officer decides that it is necessary. VMS/INFO-signs automatically according to following rules. AT LEAST ONE OF FOLLOWIN TERMS (D1...D3) FULLFILL			
(D1) DANGEROUS CONDITIONS BECAUSE OF ROAD SURFACE CONDITIONS			
Right lane friction AND Road surface temperature	μ < 0,15 AND Road surface < +2°C	'Slippery road' (144)	"DANGEROUS ROAD SURFACE CONDITIONS"
(D2) DANGEROUS CONDITIONS BECAUSE OF RAIN			
Form of rain	18 = freezing rain	'Slippery road' (144)	"FREEZING RAIN"
(D3) DANGEROUS CONDITIONS BECAUSE OF VISIBILITY			
Visibility	< 100 m	'Danger'	"POOR VISIBILITY"

Figure 14 Example on conditions for reduced speed using VSL

6.3.2 USA

The Federal Highway Administration at the Oregon Department of Transportation tested the Vaisala DSC 111 sensor in 2012 to determine its accuracy and applicability for inclusion in the prospective VSL [27].
The logic found for changing speeds was based on 4 categories:

The major weather condition categories will be:
1: dry pavement, no precipitation, high grip level
2: moist / wet pavement, light precipitation (< 1.00 mm), moderate to high grip level
3: wet pavement, moderate to high precipitation (> 1.00 mm), moderate grip level
4: ice/snow/slush/frost pavement, any precipitation, low grip level

The system is checked over a 5 to 10 minute period to confirm weather / pavement conditions. The procedure to determine appropriate control signage strategies at 3 specific ramps with a current advisory speed of 30 mph is shown in *Table* 2 below:

Table 2 : Advisory or regulatory speed limits based on weather conditions

Condition	Advisory VSL	Regulatory VSL	Speed Posted
1	ON	OFF	30 mph
2	ON	OFF	30 mph
3	OFF	ON	25 mph
4	OFF	ON	20 mph

Requirements for the VSL speed control software included that the system should not change speed limits more than once every 5 minutes, not display a speed limit below 20 mph, only display speed limits in 5 mph increments, and automatically assess weather conditions every 60 seconds.

A fog-based VSL system in the Netherlands installed defined in 1991 the following speed limit based on the following visibility conditions: [27]

- Visibility of 456 feet (140 m) – speed limit reduced to 49 mph (80 km/h),
- Visibility of 228 feet (70 m) – speed limit reduced to 37 mph (60 km/h),

There are other examples of VSL systems based on observed speeds, visibility and weather sensor data.

6.4 Conclusion

In conclusion, not much information is available in English about the utilization of VSLS based on information and data received about real time weather and road conditions at the TMCs.

To collect more information about technical solutions and control strategies and principles used by the TMCs to manage weather-controlled VSL systems, it is necessary to take contact with or carry out a survey among managers and/or operators on behalf of the Norwegian Public Roads Administration. The road infrastructure operators in the European countries, Canada and some of the Northern states in US could be possible survey respondents. Such a survey could then respond to specific questions about the technical equipment in place to collect weather and road data, the data processing, the degree of automation, the functionality and physical infrastructure of the control systems. It could also give more information about field trials carried out in these countries and their degree of success.

6.5 Examples on VSL Guidelines

6.5.1 EasyWay

EasyWay has prepared a guideline for VSL implementation including the functional and technical requirements [19]. The weather controlled VSL is defined as based on data received for various sensors like air temperature, air humidity, wind speed, visibility, road surface temperature and status (dry, wet, icy, snow thickness and precipitation intensity) sensors.

The overall system is also described as automatic and/or manual and under the supervision of the TMC operators. It was also noted that efforts should be made concerning the design of weather control model and its algorithms.

The guidelines has a set of different types of harmonisation requirements:

- Service definition
- Functional requirements
- Organisational requirements
- Technical requirements
- Common Look & Feel
- Level of service definition

The service definition is as follows:
'Variable speed limits (VSL) use variable speed signs, mandatory or advisory, as a means to help drivers to travel at an appropriate speed considering the prevailing traffic or weather conditions, in some cases supported by Speed Enforcement (SE), which mostly uses cameras to identify speeding vehicles and/or drivers.'

The functional requirements defines how the service is decomposed into physical and logical objects with interfaces that should be standardised. Some of the crucial functional requirements are listed below:

- Sensors must be adapted to the service and give input to the control system. Exceptions: For systems using clock and/or calendar control, sensors are replaced by the system clock. For manually controlled systems at road works, sensors are usually replaced by a keypad (local control unit) or similar.
  Note: Systems may include both manual and automatic functions as well as several types of sensors. This requires well defined hierarchical rules and priorities.
- Automatic and semi-automatic systems should contain models and algorithms that calculate the speed limit and transmit it to the signs. These models and algorithms can be implemented in a central control system or at the roadside.
- The signs must display the speed limit that the control system has requested and functionality must be monitored continuously by on duty staff

There is also a list of functional advices. The list below gives some examples on such advices:
- Signs should report to the control system if message activation was successful or not and possible error messages.
- Traffic Management Centre operators should be able to control the system manually and override automatic operation.
- VSL systems should have a log that stores data about signposted speed limits, error messages, etc. This is used for maintenance and legal purposes and is required in some countries.
- The control algorithms should result in speed limits that are relevant to achieve the desired effects and observance by the drivers.
- The algorithms should be constructed in an appropriate and stable way. The request for quick enough responses when safety critical circumstances occur needs to be balanced against unnecessary switching of the speed limits.
- Automatic control should be used whenever possible.
- Detector data updating frequency should be adapted to the required response times. For instance, a normal updating frequency for traffic data is between 20 seconds and one minute.

The **Organisational requirements** have no requirements but some advices. A couple of examples on advices are given below:
- VSL systems should generally be monitored by a Traffic Management Centre. This need is less prominent for automatic systems with only spot coverage.
- Road operators (Public and/or private) are responsible for planning, development and operation of the systems for variable speed limits. The corresponding guidelines, regulations and consultant papers should to be taken into account.

Technical requirements are focusing on the use of standards for Variable message signs and data. The standard EN 12966:2014 Road vertical signs - Variable message traffic signs should be used for the design of the VSL signs and the DATEX II specification should be used for the messages between the objects in the VSL control system. It is a **must** requirement that DATEX II has to be used.

Common Look & Feel requirements covers the types of signs to be used, e.g. that discontinuous signs should have white, off-white or yellow figures on a black background enclosed by a red ring. There are also requirements on how the signs should be placed above the lanes and at the roadside. There are also some advices, e.g. that fixed and variable speed limit signs must never be placed in a way that drivers can doubt which speed limit is valid. This means that fixed and variable speed limit signs should not be placed at the same cross section.

The Level of service defines 18 set of pre-defined Operating Environment (OE) were each OE is a combination of physical characteristics, network typology and traffic characteristics. The main rational behind this pre-defined OEs is to harmonise the European road network concerning the services the road users could expect in the different OE.

6.5.2 Guidelines - FWSA

The Federal Highway Administration at the U.S. Department of Transportation published guidelines for the use of VSLs in wet weather in 2012 [22]. Report FWSA-SA-12-022 provides 19 guidelines for the design, installation, operation, maintenance, and enforcement of wet weather VSL systems. Sight distance and stopping distance are considered as the primary factors to consider when setting speed limits. An example of VSL algorithm is proposed to calculate the appropriate speed limit to be displayed in case of wet weather.

Here are some examples of the guidelines:

- Guideline 3: Consider a semi-automated or automated approach for variable speed limit systems.
- Guideline 4: Incorporate weather responsive decision support into existing variable speed limit algorithms to determine the displayed speed limit.
- Guideline 5: All speed limit algorithms and manual display calculations should be approved by a traffic engineering professional.
- Guideline 8: Display variable speed limit changes for at least 1 minute.
- Guideline 11: Use Changeable Message Signs (CMS) to communicate reasons for speed reduction.
- Guideline 14: Install appropriate weather sensors or use accurate weather data at problem locations.

7 Impacts of Variable Speed Limits (VSL)

7.1 Traffic Safety

In 1999, the Federal Highway Administration conducted a study to identify noteworthy practices and technologies that may have value in the United States [24]. Their investigation showed that, for example, variable speed limit signs and lane control signals installed on the autobahn in Germany would generate cost savings due to crash reductions that would be equal to the cost of the system within two to three years of deployment. In Amsterdam, Netherlands the system reportedly reduced the "overall accident rate" by 23 percent, reduced the "serious accident rate" by 35 percent, and reduced the "secondary accident rate" by 46 percent. In Germany, the accident rate fell by 20 percent in areas where variable speed limit signs and lane control signals were used to warn drivers of congested conditions. On a comparable section of autobahn without lane control, accidents increased by 10 percent in the same time period.

In the EasyWay VIKING Overview of evaluations (2013) in the EasyWay VIKING region i.e. Finland, Sweden, Norway, Denmark, Lithuania, Estonia and Northern Germany, presented several experiences with the use of VSL [20]. The majority of road user are positive to the implementation of VSLs.

Trials with VSL carried out in Sweden (2003-2008) investigated mandatory speed limits adapted to traffic conditions by reducing the speed limit when the traffic was dense. The results showed that sudden breaking at low speeds were less common and the number of accidents per million vehicle kilometres were reduced by 20 %. The use of VSL makes the traffic flow smoother and less sudden braking.

In Germany, the Motorway Control System concept (2006) including VSL together with overtaking bans and congestion warnings on A1 Bremen showed a decrease in the number of accidents by 20 % and congestion.
In Gothenburg (Sweden), the effect of time controlled VLS on traffic safety, traffic flow and average speed of vehicles have been evaluated (2008-2009). Results showed that the variable speed limits had no negative impact but did not increase the flow capacity. However, the signs indicated to drivers to pay more attention, which could be a reason for the fewer accidents. [20]

7.2 Speed reduction

The EasyWay VIKING Overview of evaluations report (2013) concluded that the results from Finland and Sweden showed that drivers comply better with variable speed limits than static speed limits. This means that the variation of speeds is reduced to some extent.

On poor weather and road surface conditions, drivers reduced their speeds by 2-5 km/h more than they would do it on their own. The effects are larger, when the adverse conditions are not so easy to detect. In very poor conditions, the drivers decreased their speeds by more than 10 km/h. In good conditions, when the speed limits are increased, drivers increase their speed by 2-5 km/h. High-quality speed control systems decreased injury accident risks by ca 10 % in the winter period. Outside the winter period, the decrease is of 6 %. The benefit-cost ratio estimation varied between 1 and 2 for the Finnish and Swedish implementations. [20]

In Finland, the effects of Weather controlled Variable message signs (2001) showed that drivers seek cues on potential hazards, testing the slipperiness of the road and had more careful driving behaviour. Lowering the speed limit from 100 to 80 km/h decreased by an average of 3.4 km/h in winter. The system proved to be more effective when bad weather and road conditions are difficult to be detected [26]. In addition, in

Finland, the combination of VSL and automatic speed enforcement was assessed to be beneficial on road sections where drivers should drive slowly because of bad weather conditions and at intersection with high traffic volumes. The use of the automatic speed enforcement could reinforce the effect of the VSL and then the result could be greater than with the VSL alone [20].

The results from the Dynamax programme of field operational test (FOT) for assessment of effects of dynamic speed limits on Dutch motorways (2011) showed positive effects with moderate side effects: In the evaluation A12 Bodegraven Woerden rain application, drivers react directly when the speed limit was reduced to 100 or 80 km/h and they subsequently adapt their speed much more smoothly, without abrupt breaking and also earlier (before it rains). The average speed was reduced from 9 to 13 km/h and traffic safety was considered as improved substantially. [25]

In addition, VSL have also been tested at intersections in Denmark, Finland and Sweden. VSL, the average vehicle speeds decreased by up to 17 km/h (E22, Sweden) on interurban roads and up to 13 km/h (Gladsaxe, Denmark) in urban areas. Typical results are 8-16 km/h reduction with a reduced speed limit of 20 km/h, 4-8 km/h for a 10 km/h lower speed limit, 0-4 km/h reduction for an unchanged speed limit. The number of accidents at intersections were too small for statistical analysis. [20]

The VSL may also have an impact on ITS services reading the VSL, e.g. Intelligent Speed Adaption and ITS services enabling autonomous vehicles.

7.3 Conclusion

Even if the effect on the number of accidents was difficult to quantify in some studies due to limited data and the side effects of other factors, several studies showed a positive impact on traffic safety and on the reduction of the average speed of the vehicles. Reduced travel times, decreased fuel consumption and lower emissions were also cited as benefits of the VSL system.

The success of an effective weather control system was reported as based on an efficient recognition of hazardous weather and road conditions, use of variable slippery road signs to support the variable speed limit system and moderately use of the highest speed limits.

The experience in using VSLs is reported as positive in terms of traffic safety, traffic flow, and driver acceptance. However some issues should be addressed before implementing the systems at a national level. There are issues associated with the legal requirements imposed by the law, the procedures related to the choice, design and location of the speed limits, and the associated enforcement policies.

8 Norwegian guidelines regarding introduction of weather-controlled VSL

The implementation of variable speed limits due to weather and road surface condition is per October 2016 not authorised by the Norwegian guidelines [31] on variable traffic signs. The guidelines states the following:

Reduction of the speed limit due to difficult weather or driving condition shall not take place. Strong wind is the only exception. Automatic weather and road surface condition measurements and speed limit control criteria are so far not reliable enough to be used in variable speed limit system.

The Norwegian Public Roads Administration has worked with implementing variable speed limits and new guidelines for the use of variable speed limits. Variable speed limits due to weather and road surface condition has been one of the issues that have been raised in this work but there are no guidelines so far (Oct 2016) describing if and when variable speed limits could be used.

It is recommended that the guidelines should cover the following aspects:

- The authorisation to use variable speed limits due to weather and road conditions
- The prerequisites that should be fulfilled concerning
    - parameters that should be used for an automatic and/or manual selection of variable speed limits
    - parameter limits and the algorithm used for an automatic and/or manual selection of variable speed limits
    - Reliability, availability and accuracy of the information collected and used for varying the speed limits
    - The minimum period of time that a speed limit should be shown
    - The minimum length of road section that should be subject to a decreased/increased speed limit
    - Verification of the weather and road conditions before a speed limit is changed
- The choice between automatic and manual control for the different speed limits
- The speed steps to be used when changing the speed limits: 10 and/or 20 km/h
- The maximum distance between the variable speed limits signs
- The information signs (variable message signs) to accompany and explain the reason for the reduced/increased speed limit
- The monitoring of the variable speed limit signs and the logging of the speeds shown
- The enforcement of variable speed limits

9 A case study at E18, Vestfold County, Norway

9.1 Introduction

Data was collected from several weather stations along E18 for the winters of 2014/2015 and 2015/2016. In a detailed memo [30], a statistical analysis of this data set was carried out, which is summarized in this section. For the following five weather stations, data was collected for both the two winter periods and therefore became the focus in this study:

- Hanekleiva
- Fokserød
- Grelland
- Gulli Nord
- Rødbøl

The geographical position of these weather stations are shown in Figure 15 (red squares). The figure also shows the points where traffic volume data were collected as this type of data is not collected at the weather stations along E18 in Vestfold County, Norway.

Figure 15 Geographical position of the five studied weather and traffic volume stations

The weather stations collect amongst others the following data:

- Place and time
- Air temperature
- Relative humidity
- Surface temperature
- Friction
- Precipitation
- Wind direction and speed
- Road surface water, snow and ice layer thickness
- Pictures

The Vaisala Remote Road Surface State sensor DSC111 and Vaisala Remote Road surface temperature Sensor DST111 collects the following data: air temperature, relative humidity, dew point, surface temperature, surface status, coverage thickness, level of grip (friction) and amount of water, snow and ice.

The road has four lanes but the DSC111 sensor is usually aimed at the lane closest to the sensor. The camera installed is a doome kamera Axis P5512-E.

9.2 Road accidents

During the period between February 2010 and March 2016 there has been 24 accidents registered at E18 in Vestfold where the road surface condition has been marked as Road surface covered by snow and/or ice, Road surface partly covered by snow and/or ice or Slippery road [34]. As seen in Figure 16 most of the accidents took place on the E18 section north of Holmestrand.

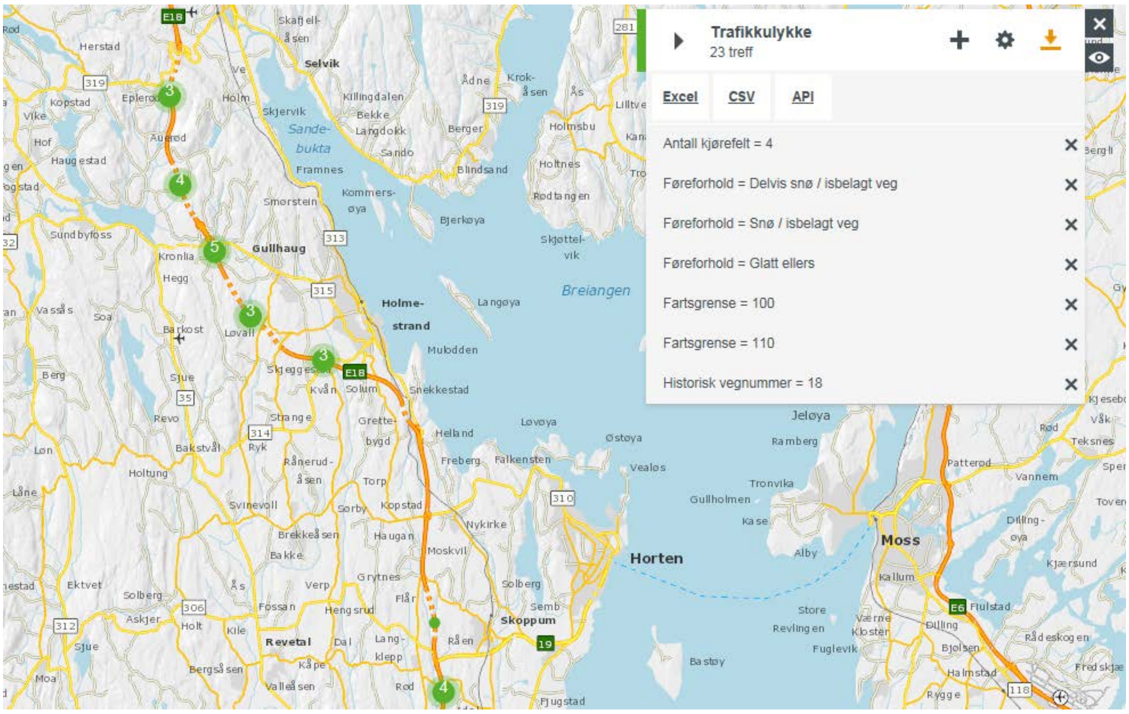


Figure 16 Geographical position of the majority of the road accidents

A more detailed study of the accident data found in [34] showed that:

- 10 of the accidents took place during daylight
- 13 of the accidents were single accidents, i.e. the vehicle went off the road without involving other vehicles
- The air temperature varied from -14 to +2°C
- 7 persons were severely injured and 34 persons were slightly injured
- 7 of the accidents happened inside a tunnel or very close to a tunnel entry/exit
- 5 of the accidents happened in 2010, 3 in 2011, 6 in 2012, 4 in 2013, 2 in 2014, 2 in 2015 and 2 in 2016

The speed limit of 110 km/h on E18 in Vestfold was introduced in June 2014. It seems difficult to find patterns and relationships in the accidents during winter time without a more detailed study of the police investigations and documents and the statements of the involved drivers.

9.3 Data description

For the 5 RWIS stations showed in Figure 15 data was collected every 10 minutes with the most interesting data fields being: Estimated value of friction, amount of snow, ice and water, wind speed, air temperature, road surface temperature, relative humidity and dew point temperature. The main focus will be on the friction values, and in total there are 80 380 registrations in 2014/2015 and 103 304 registrations in 2015/2016. Table 3 shows a summary of the amount of missing data, for each station each year.

Table 3 : The number of data points for winter period and weather station

2015			
Weather station	**Period**	**Number of days**	**Number of data points**
Hanekleiva	07.01.2015-01.05.2015	106 (115)	11366 (15264)
Grelland	07.01.2015-01.05.2015	106 (115)	11335 (15264)
Gulli Nord	01.01.2015-01.05.2015	112 (121)	11233 (16128)
Fokserød	07.01.2015-01.05.2015	106 (115)	11293 (15264)
Rødbøl	01.01.2015-30.04.2015	110 (120)	11379 (17280)
2016			
Weather station	**Period**	**Number of days**	**Number of data points**
Hanekleiva	01.11.2015-31.03.2016	152 (152)	21200 (21888)
Grelland	01.11.2015-31.03.2015	134 (152)	18404 (19296)
Gulli Nord	01.11.2015-31.03.2015	152 (152)	21154 (21888)
Fokserød	01.11.2015-31.03.2015	152 (152)	20942 (21888)
Rødbøl	01.11.2015-31.03.2015	152 (152)	21209 (21888)

Column 3 shows the number of days with registrations of friction values (with the total number of days for the registration period in parenthesis). Column 4 shows the number of data points that does not filter out due to missing values for either friction or some of the other parameters measured at the stations. The number in parenthesis shows the total number of 10 minutes intervals for the registration period. It should be noted that the data are collected via two different channels in 2015 and 2016. The data from 2015 are not complete as there were some problems with the data storage and transfer. The data from 2016 shows a much better availability and the average for the five stations shows an availability of 96.3 %. By availability is meant that there is a complete record received from the weather station were all parameters have a realistic value.

In *Table 4* the number of friction values below 0.6 and 0.2 are counted for each year and weather station. The Hanekleiva station is for both years reporting the largest amount of slippery roads.

Table 4: The amount of estimated friction levels below 0.6 and 0.2 for each weather station and winter period.

	2015		2016	
Weather station	**Friction < 0.6**	**Friction < 0.2**	**Friction < 0.6**	**Friction < 0.2**
Hanekleiva	11.9 % (1363)	3.5 % (420)	5.7 % (1207)	1.1 % (240)
Grelland	3.1 % (359)	1.0 % (117)	5.3 % (980)	2.1 % (381)
Gulli Nord	4.9 % (566)	3.2 % (380)	4.1 % (863)	1.3 % (275)
Fokserød	2.7 % (311)	1.2 % (138)	5.0 % (1051)	2.4 % (516)
Rødbøl	5.3 % (624)	4.3 % (511)	2.9 % (607)	1.1 % (229)

The number of observations are shown in parenthesis.

9.4 Statistical analysis - Results

The estimated friction values are a function of the road condition, i.e. the other parameters measured at the weather stations. In the detailed memo [30], these dependencies are investigated using descriptive and inferential statistical analysis. For instance, time series of friction values are plotted alongside the other covariates, see Figure 17 for an example with friction, ice, water, and snow for Hanekleiva. As one can see there seems to be a significant dependency between low friction values and the presence of snow, ice and water on the road surface. This dependencies were expected and confirms the reliability of the 'grip' value (friction) estimated by the Vaisala sensors. These parameters are in fact the three parameters that correlates the strongest with the estimated friction value.

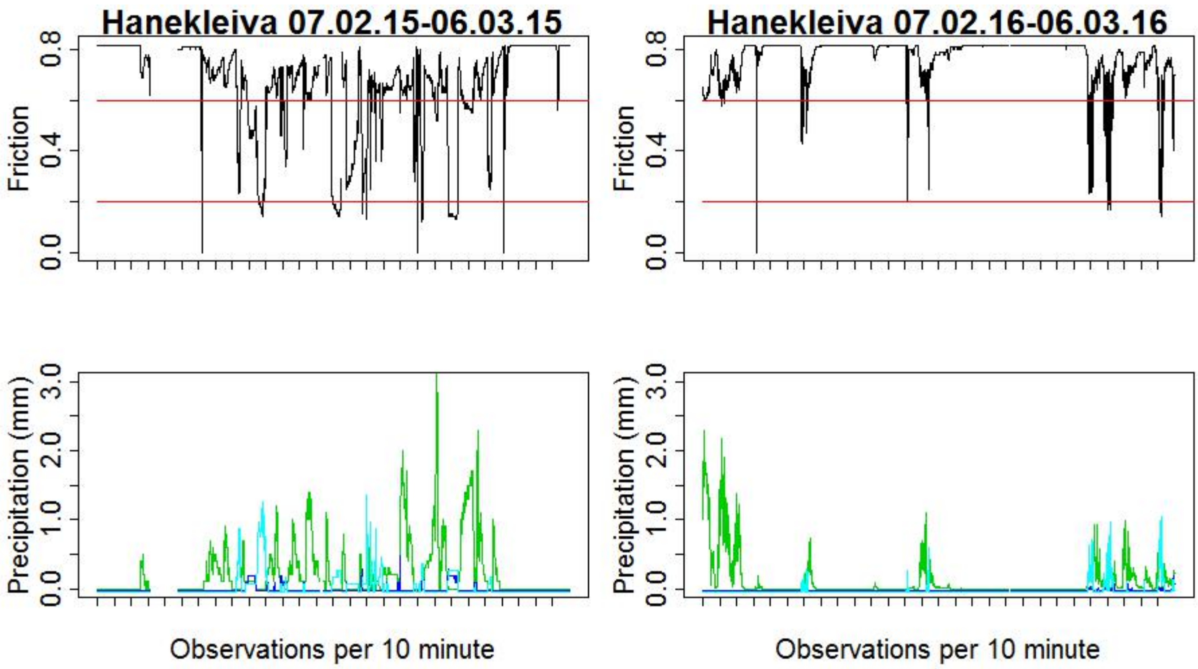


Figure 17 Time series of friction and precipitation on the road

The amount of water is shown in green, ice in dark blue, and snow in light blue.

Both a GLM model (Generalised linear models) and a k-nearest neighbour model was fitted to the data to see if it was possible to predict friction as a function of the other parameters measured at the weather stations. The k-nearest neighbour model showed great potential using all parameters (including snow, water and ice measurements). As measurements of snow, water and ice demands extra equipment at the weather stations is was desirable to check whether a k-nearest neighbour model with only the parameters wind speed, air temperature, road surface temperature, relative humidity and dew point temperature was sufficient to obtain good predictions of friction. However, this did not give satisfactory results.

9.5 A more detailed case study: Time period 07.01.2016 – 14.01.2016

In this time period the weather situation along E18 was particularly challenging. In Figure 18 the estimated friction values for this time period are plotted along with the measured amount of snow, ice and water for two of the weather stations.

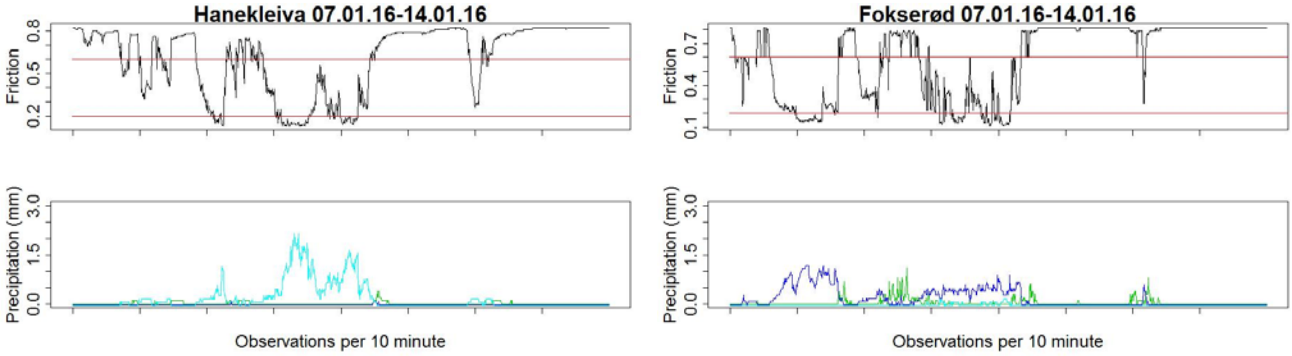


Figure 18 Time series of friction and precipitation on the road

The amount of water is shown in green, ice in dark blue, and snow in light blue.

As one can see from this figure the amount of time spent in a state with low friction values is high within this time period. Photographs collected every 10 minute was obtained and studied for this time period from all weather stations. It was verified that the driving conditions were indeed very challenging. To investigate how traffic was affected by this weather situation, we collected data from loop-detectors close to the weather stations and compared the mean speed of passing vehicles within each 10-minute interval to the estimated friction value. Some results for this study can be seen in Figure 19, and as we can see there seems to be a clear correlation between vehicle speed and the measured weather condition.

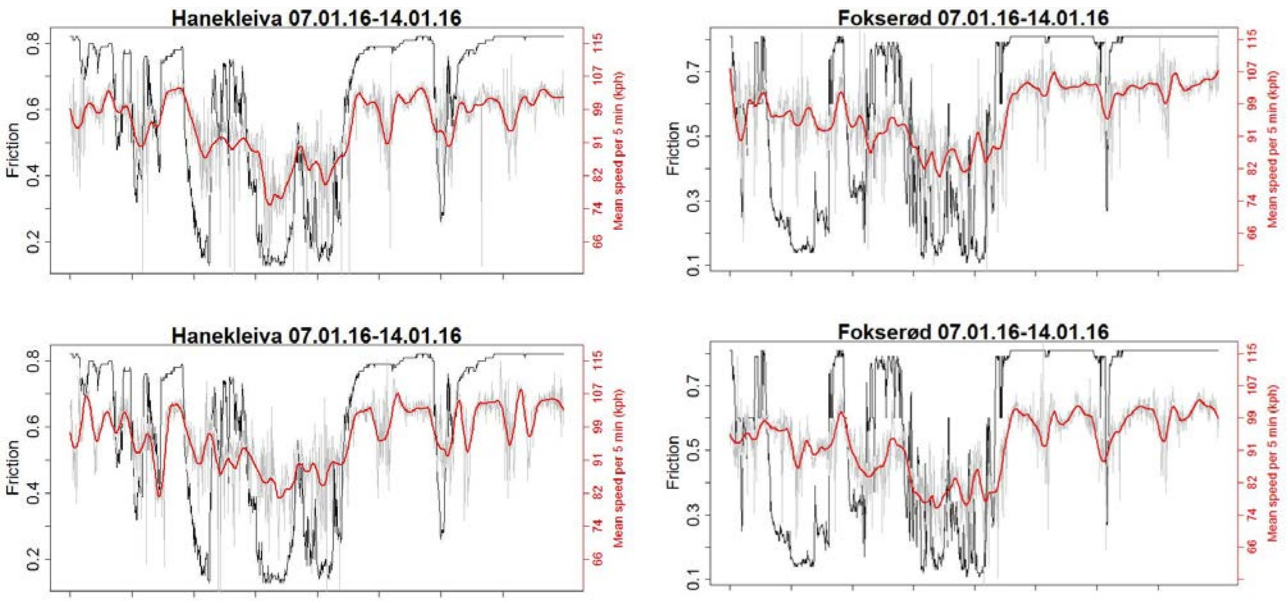


Figure 19 Time series of friction (black), mean speed (grey), and smoothed mean speed (red) for two of the weather station and for loop detectors close by in both driving directions.

This result corresponds well with intuition, and do to some degree validate the measurements obtained at the weather stations. Again, more details can be found in the memo.

Figure 19 shows the smoothed mean speed in both driving directions. There are however some differences in the four lanes concerning speed (red line) as shown in Figure 20.

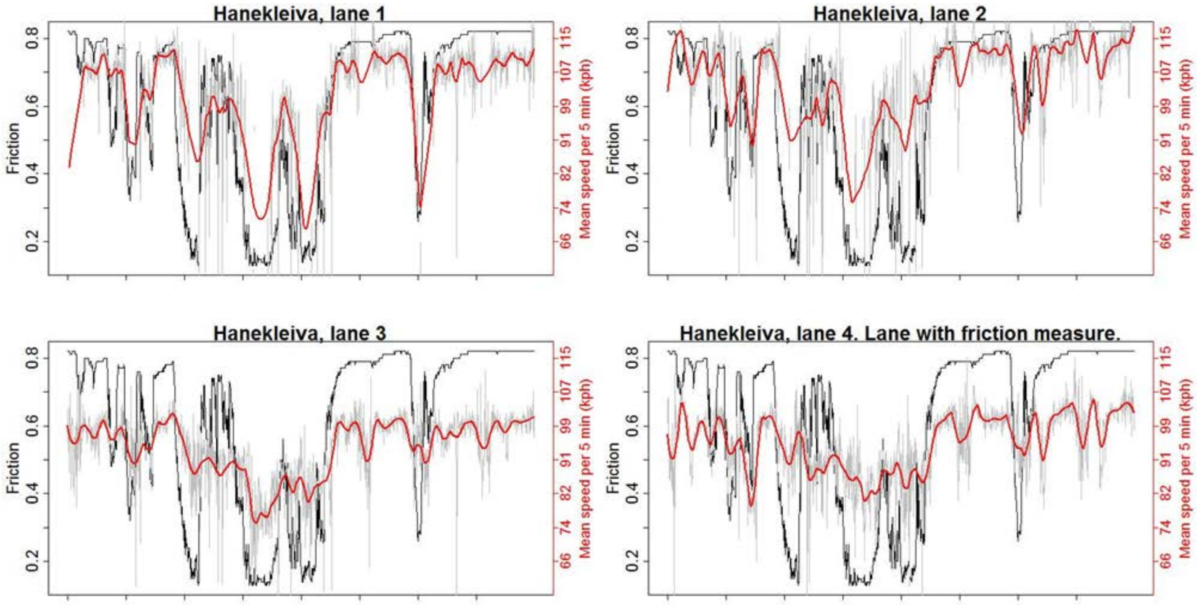


Figure 20 Speed measurements in the four lanes at Hanekleiva (Hanekleiva Syd)

The figure shows that all lanes have a pattern that correlates to the friction measurement but the speeds in the right lanes in each direction, i.e. the lanes closest to the road shoulder, are lower than the speed in the lanes closest to the middle of the road (left lane in each direction).

Given that both friction and traffic volumes are given for 10 minute intervals, the drivers speed choice is investigated as a function of these two variables. In particular, the mean speed and variance of passing vehicles are calculated for the friction levels below 0.2, between 0.2 and 0.6, and above 0.6. The results can be seen in the three tables below, where Table 5 shows the number of observations for each class, Table 6 shows the calculated mean speed for passing traffic, and Table 7 shows the calculated standard deviation for the same. Only observations from the lanes with a friction measurement is used in these calculations. That is lane 4, 3, 4, 3 and 4 for Hanekleiva, Grelland, Gulli Nord, Fokserød and Rødbøl, respectively. From Table 6 we see a clear mean speed reduction as the friction level decreases. However, the traffic demand at these limits seems more or less unchanged. For the variance of speed there seems to be a small reduction as a function of increasing traffic volume, but this study is unable to show any decrease in the variance as a function of decreasing friction level. Note that no test of statistical significance are performed for these results, which should be done in a more detailed and conclusive study, as the scope of these results are to give an indication of the possible effects.

Table 5: The number of observations within each classification of traffic volume and friction value

Traffic volume / Friction level	Low traffic 10-39	Medium traffic 40-79	High traffic >79
<0.2	256	134	20
0.2-0.6	366	454	146
>0.6	764	1621	780

Table 6: The mean speed within each classification of traffic volume and friction value

Traffic volume / Friction level	Low traffic 10-39	Medium traffic 40-79	High traffic >79
<0.2	82.59	81.18	83.81
0.2-0.6	91.24	88.12	86.26
>0.6	97.69	96.58	96.90

Table 7: The standard deviation within each classification of traffic volume and friction value

Traffic volume / Friction level	Low traffic 10-39	Medium traffic 40-79	High traffic >79
<0.2	14.11	13.77	12.03
0.2-0.6	13.64	12.99	13.01
>0.6	14.29	13.14	13.13

9.6 Road surface friction coefficient and recommended limits

One of the main questions to be resolved concerning the implementation of road condition and weather based variable speed limits is, for which values of the road surface friction should the speed limits be decreased/increased. The question is discussed below.

The Swedish transport administration (Trafikverket) has been testing variable speed limits since 2003 and some of the tests have implemented weather controlled speed limits. One of the tests took place at E6 Halland at the Swedish west coast from Spring 2005 to End 2007. The speed limits were set manually by the operators at the Traffic Management Centre in Gothenburg. The speed limits were controlled according to the expected friction coefficient on the road that was calculated based on information on temperature, moisture, wind speed and wind direction. The following values were used for controlling the speed limit:

- No adverse weather condition: speed limit 120 km/h
- Friction expected to be 0.4 (moderate rain, light snowfall): speed limit 110 km/h
- Friction expected to be 0.3 (heavy rain, moderate snowfall): speed limit 100 km/h
- Friction expected to be 0.2 (very heavy rain, heavy ice formation): speed limit 80 km/h
- Friction expected to 0.1 (cloudburst, very heavy ice formation):speed limit 60 km/h

The Finnish transport agency (Trafikverket) has published a guide for variable speed limit and info sign policy. The road condition is classified in 4 classes:

- Good conditions (A)
- Reduced conditions (B)
- Poor conditions (C)
- Dangerous conditions (D)

At Good conditions the speed limit is 120 km/h (100 km/h during winter conditions). At Reduced conditions the speed limit is 100 km/h. At Poor conditions the speed limit is 80 km/h and at Dangerous conditions the speed limit is 60 km/h. The guidelines includes several parameters that should be fulfilled/not fulfilled defining the road condition at any moment. From the available information it seems as if the selection of the speed limit is automated for A – C and manually for category D.

The parameters used in the matrix that defines the road conditions are the following:

- Right and/or left lane condition/state that can be dry, damp, wet, wet and salted, damp and salted, sleet or ice
- Road surface temperature with a +2°C as a critical value
- Right lane friction with the values 0.4, 0.3 and 0.15 as critical values being input the categorisation
- Precipitation that can be No rain, weak, moderate, heavy rain, freezing drizzle and freezing rain. Other types of precipitation is Light snow or sleet, moderate snow or sleet and heavy snow or sleet.
- Visibility with the values 600 meters, 300 meters, 200 meters and 100 meters as critical values being input to the categorisation.
- Wind that can be Mean wind or Max wind. Critical values used for classification are 12 m/s and 17 m/s.
- Sun up

The parameters listed above are not only used for variable speed limits (VSL) but also for variable messages sign (VMS) to the road users. The traffic signs Slippery road and Danger are supported by VMS explaining the reason why the Slippery road or Danger sign has been activated, e.g. freezing rain or poor visibility.

Concerning the road surface friction the following values are used as one of several parameters to define the road condition class:

- Good condition $\mu \geq 0.4$
- Reduced condition $0.40 < \mu \geq 0.3$
- Poor condition $0.30 < \mu \geq 0.15$
- Dangerous condition $\mu < 0.15$

The Norwegian guidelines for road building recommends that the road surface friction should be better than 0.40 at the speed of 60 km/h. The friction should be measured on a clean and wet road surface, i.e. water thickness is 0.5 mm. On roads with a speed limit of 80 km/h or more, the friction should be above 0.5. This is 25 % higher than the similar requirement for the Finnish high speed roads. The previous version of the Norwegian guidelines for winter maintenance advised preventive salting if the road surface friction was expected to be lower than 0.4 for bare road strategy.

It is important that the speed limits that are used for controlling the traffic during reduced, poor and dangerous road conditions are accepted by a majority (85 % fractile) of the drivers avoiding too many speed violators and loss of respect for traffic signs and control. Figure 21 shows the friction estimated by the roadside equipment (black line), the 5 minutes average speed of the vehicles (grey line) and the smoothed average speed (red line) in both directions. The figure shows that the average speeds are around 100 km/h during periods when the estimated friction is in the range of 0.6 – 0.8. The average speed drops during periods where the road surface friction is estimated below 0.6 and goes down as low as 75 km/h during longer periods with low friction. The same tendencies are found for other roadside stations at E18.

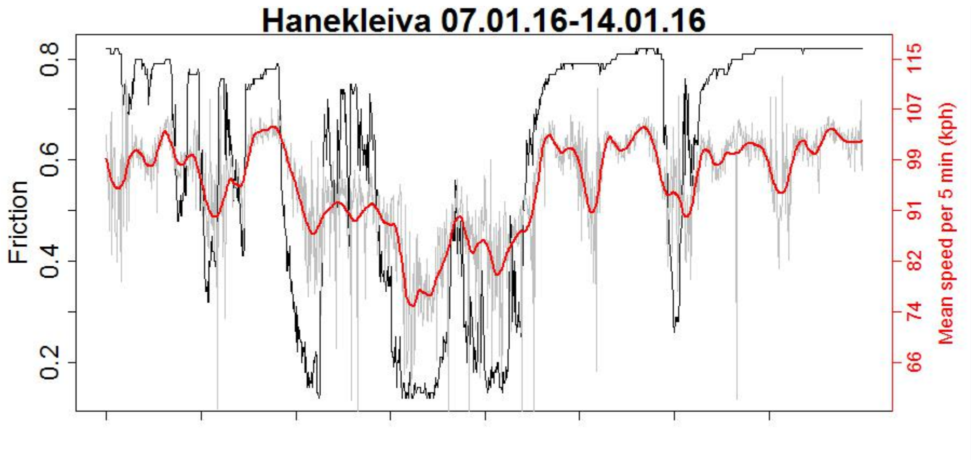


Figure 21 Estimated friction, average and smoothed average speed at Hanekleiva

Figure 22 shows the precipitation and speed variations and correlations at Hanekleiva in the same lane as the friction measurement the second and third week in January 2016. Some interesting points in the figures (numbered from 1 to 9) are discussed below.

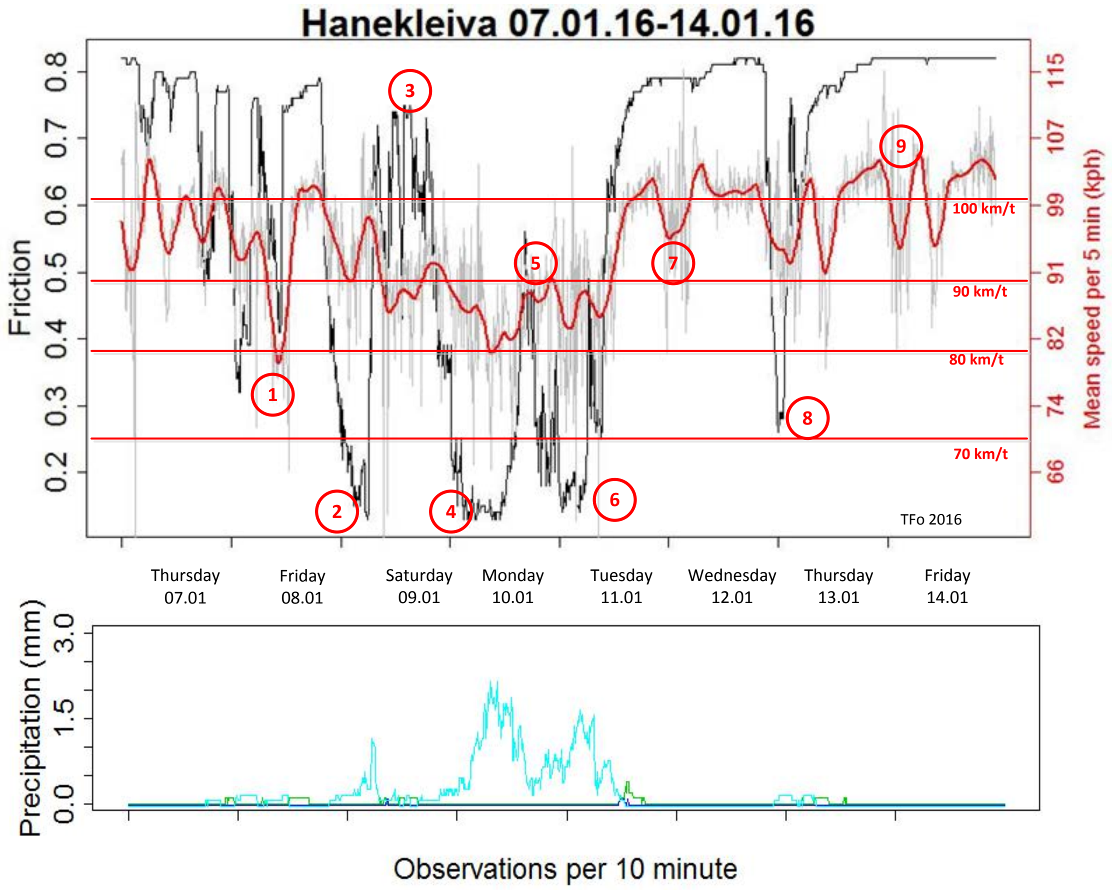


Figure 22 Friction, precipitation and speed variations and correlations at Hanekleiva

1. Point 1 shows a drop in the friction from about 0.76 down to below 0.4 for a very short period. At the same time there is a drop in the average speed from 95 - 100 km/h down to 80 km/h. The reduced road conditions seems to be caused by snow (light blue line) and water (green line) on the road surface. As soon as the snow melts and the road surface becomes more or less dry, the average speed increases up to about 100 km/h.
2. At point 2 there is a new snowfall that causes the estimated friction to go down to below 0.1 at the lowest and for a short period. The average speed drops from 105 km/h down to around 90 km/h.
3. At Point 3 there are quite some variations in the estimated friction but the average speed remains around 90 km/h. From the precipitation diagram it seems as if there is a mixture of snow and water that causes the driver to keep a lower speed.
4. At point 4 there is a new snowfall which causes the friction to drop down to below 0.1 for a longer period. The average speed drops as well and down to 80 km/h at the lowest. The speed then increases as the friction increases. It should be taken into consideration that snowfalls during the night might have a bigger impact on the speed than snowfalls during daylight.
5. At point 5 the average speed has increased to 90 km/h even if the friction is reduced and there is still some precipitation on the road surface.
6. At point 6 there is a new snowfall that has caused the estimated friction to drop below 0.1 and the average speed to drop down to 85 km/h for a short period. The combination of the

snowfall and the darkness may have an impact on the reduced speed. The snow on the road surface turns to water and the speed increases again up to around 100 km/h.

7. At point 7 there is a drop in the average speed while there is no drop in the friction. This takes place during the night and may be an indication that speeds are lower during night caused by lower visibility and/or there are heavier and slower commercial vehicles during night and less private cars.
8. At point 8 there is a small snowfall and the speed and friction drops again. However, again the darkness and the mix of vehicles could be the most important reason for the reduction in speed.
9. At point 9 there is a drop in the speed but there is no similar drop in the friction and the road surface has apparently no precipitation. The speed drop is during the night and it strengthen the assumption that the mix between light and heavy vehicles is different during night time compared to daytime. This is even more evident for another roadside station named Rødbøl, see Figure 23. There is no precipitation during the last four days and no longer periods with low friction but there are 3 evident drops in the speed during night.

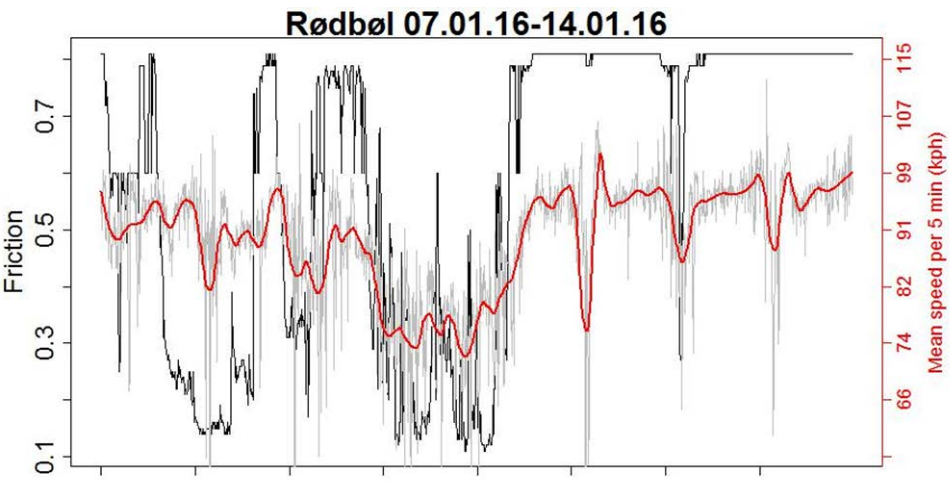


Figure 23 Friction and speed variations and correlations at Rødbøl

Figure 24 shows the estimated friction and speed for all 5 stations for the 8 days of data collection. The figure shows the speed and friction in the lanes with the friction measurements.

The smoothed average speed chosen by the drivers has apparently a good correlation with the estimated friction except for the third day where the friction estimated would indicate that the drivers would choose a speed around 100 km/h. However, the figure shows that the drivers chooses to drive more carefully with a speed around 90 km/h. This implies that the road condition was not captured correctly by the roadside equipment and that the drivers eventually would not be warned about the reduced road condition by a lower speed limit.

The most obvious explanation on the difference between the road condition described by the estimated friction and the road condition perceived by the drivers was found by studying the pictures from roadside stations. The pictures showed that although the road conditions in the right lane seemed to correlate with the estimated road surface friction, the road condition in the left lane was different. As there was almost no snow or slush in the right lane it was evident from the pictures that the road conditions were rather different in the left lane. This caused that most drivers stayed in the right lane where the speed usually is lower than in the left lane. Passing a vehicle by changing from the right lane to the left lane with a higher speed than 90 km/h has apparently been perceived as dangerous or risky and the most drivers have stayed in the right lane with the lower speed. *Hence, this emphasises the importance of having road surface sensors for all lanes at a weather station.* If there are two parallel lanes in one direction and only one sensor the drivers may be advised a speed that is much higher than it should be according to the weather and road surface conditions.

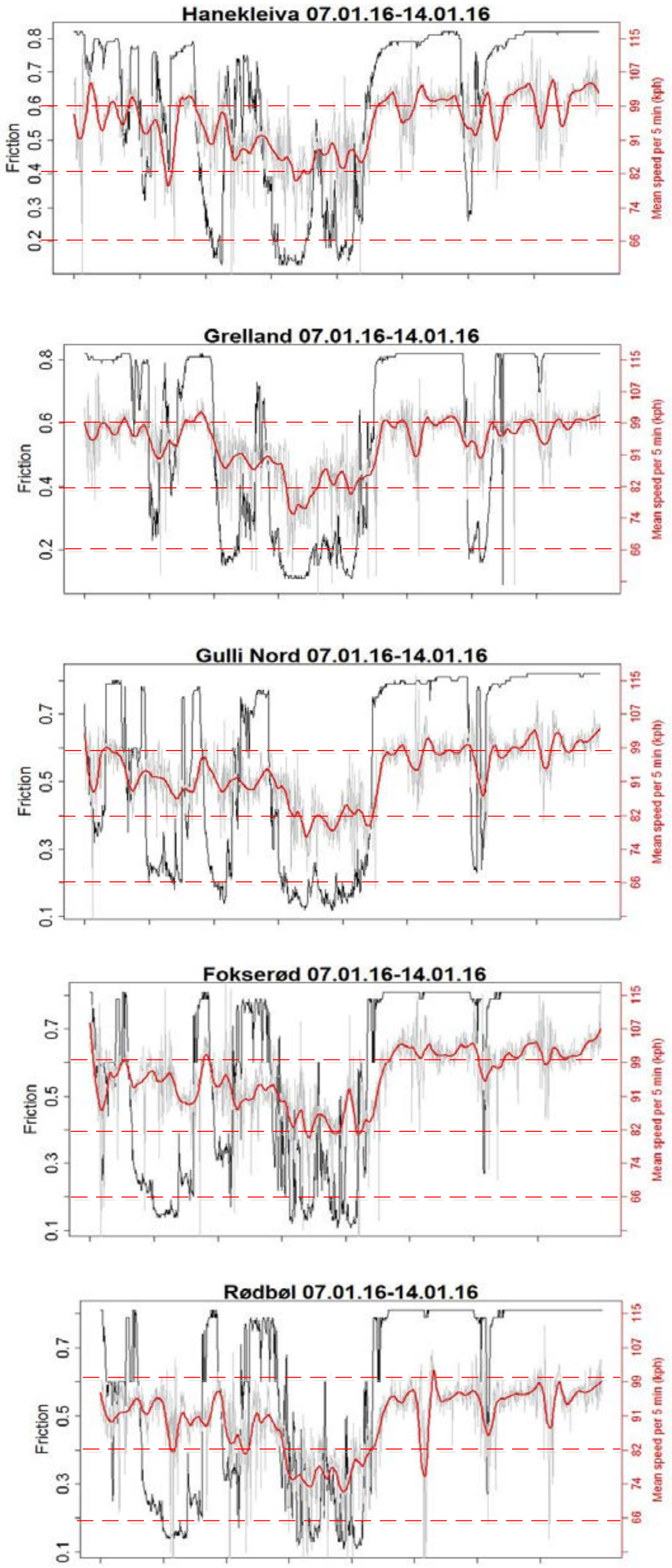


Figure 24 Friction and speed variations and correlations for 5 roadside stations

10 A proposal for a control of speed limits based on estimated friction

The proposal is based on the following assumptions/observations, referring to Figure 24:

- If the road surface friction is more than 0.6 it seems from the registered speeds that the road conditions will have little or no impact on the drivers concerning their choice of speed. The average speed will be around 100 – 105 km/h during winter time. However, at Rødbøl the average speed seems to be a little bit lower than the other four stations. There might be geometric reasons for this difference but this has not been investigated further in this project.
- If the road surface friction is less than 0.20 - 0.25 it seems as if this has a major impact on the drivers concerning their choice of speed. From the registered speed it seems as if many drivers choose to drive with a speed in the range of 75 – 85 km/h.
- If the road surface friction is in the range 0.3 - 0.5 it seems from Figure 24 that many drivers selects a speed around 90 km/h ± 5 km/h.

Based on the assumptions/observations described above a possible relation between the estimated road surface friction and the recommended speed limit is shown in Table 8.

Table 8: Proposed relation between road surface friction and recommended speed limit

Road surface friction	Proposed speed limit	Comment
$\mu \geq 0.6$	110	
$0.6 > \mu \geq 0.5$	100	The friction data curves shows in many cases that if the friction drops below 0.6 it continuous to drop down to a much lower level. Hence, it could be beneficial to use 100 km/h as the first reduction and warning of the coming reduced road surface condition. This would also cause a smoother reduction of the high speeds compared to reducing the speed from 110 km/h down to 90 km/h and probably cause less differences between the individual vehicle speeds which again has a positive traffic safety impact.
$0.5 > \mu \geq 0.3$	90	
$0.3 > \mu \geq 0.2$	80	
$\mu < 0.2$	70	Extreme situations

Applying the values in Table 8 on the road section linked to the Hanekleiva roadside station on January 10th, 2016, would have resulted in that the speed limits would vary between 90 km/h, 80 km/h and 70 km/h from 00:00 to 24:00. An approximate illustration of how the speed limit would vary between 00:00 and 24:00 is shown in Figure 25.

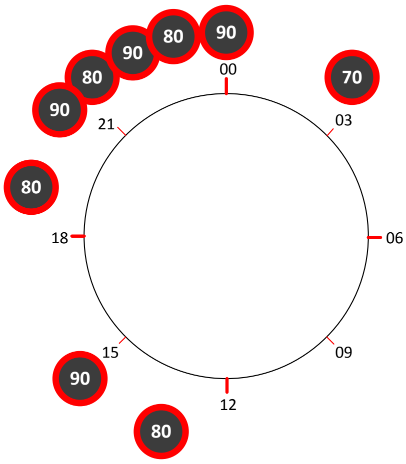


Figure 25 An approximate illustration of speed limit variation during 24 hours at Hanekleiva

As seen from Figure 24 the average speed chosen by the drivers is around 80 km/h in the period where the speed limit would have been 70 km/h. The average speed is about 30 km/h lower than the ordinary speed limit which also indicates difficult driving conditions. Figure 24 also shows that the average speed during all 24 hours on the 10th of January were more or less always around or below 90 km/h. Hence, there is a good correlation between the speed limit that would have been chosen by a system/operator based on the road surface friction estimated and the speed preferred/chosen by the average driver.

Figure 26 shows the individual speed profiles for the four lanes at Hanekleiva at Jan 10, 2016 (blue squares). Lane 2 and 4 are in the same direction and lane 4 is the lane close to the road shoulder and the lane with the friction estimation. Lane 1 and 3 are in the opposite direction with lane 3 as the lane closest to the road shoulder. The differences in the speed profiles are possibly caused by different driving conditions in the lanes, different traffic volumes and different types of vehicles, e.g. more heavy goods vehicles in the lanes number 3 and 4. This could be further investigated by a more detailed study of the pictures from the weather station at Hanekleiva collected on Jan 10, 2016.

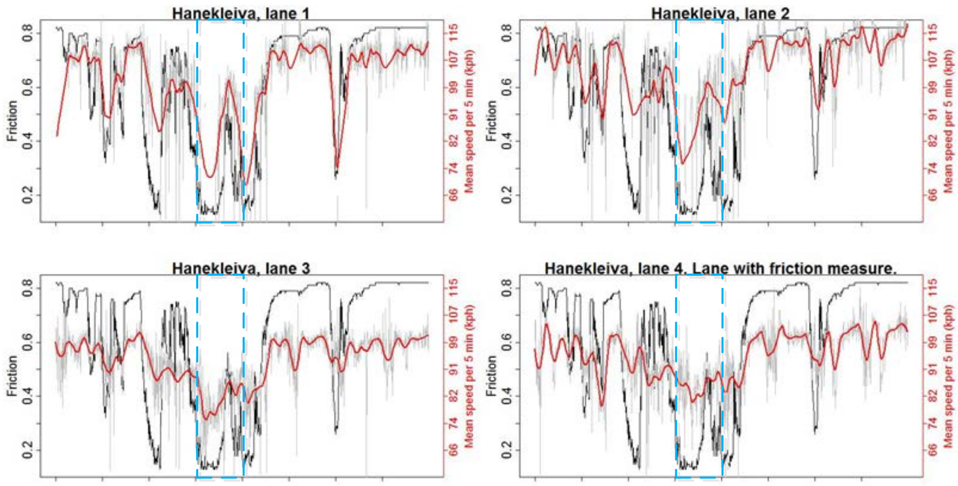


Figure 26 Differences in the speed in the four lanes at Hanekleiva Jan 10, 2016

The long period with a speed limit as low as 70 km/h should trigger a warning or urgent message to the persons in charge of the road maintenance that the maintenance routines should be checked to see if the road owner requirements have been met during the long period of reduced speed.

11 Recommendations

Based on the feasibility study and the data collected from the weather stations at E18 in Vestfold during winter 2014/2015 and 2015/2016 we have the following recommendations:

Weather and road condition information systems

The implementation of such systems are expected to have the following impacts by the provision of more reliable, accurate and available information on the weather and road condition:

- Enable road users to plan their travels avoiding bad weather and road conditions by cancelling the travel or delaying the travel until the conditions allow for a more safe and efficient journey
- Enable road users to be better prepared for their journey concerning travel time, delays and equipment for bad weather in case cancellation or delay of the travel is not an option
- Enable winter maintenance contractors to provide a more efficient maintenance by automatic warnings from the weather and road condition information system when the conditions call for maintenance activities from the contactors
- Enable fleet managers to plan, monitor and control their vehicle fleets used for transport of goods and persons (public transport) during periods with reduced weather and road conditions
- Enable road operators and road owners to monitor the road conditions and compare them with the requirements to the contractors verifying that the contractors fulfil the requirements
- Enable road operators to monitor the status of the roads and the traffic flows and control the traffic flows in case the weather and road conditions require such control, e.g. closing roads at mountain passes during wintertime or reducing speed at heavy precipitation or lack of sight.
- Enable road operators to monitor the status of the weather and roads informing the roads users about the conditions either through variable message signs along the road, by information directly to in-vehicle equipment or via other media like internet and broadcasting
- Provide ITS application developers with data that could be used for developing new services and products to the benefit of the users of road transport services

Recommendation

We recommend that the Norwegian Public Roads Administration continues its work in further development of the existing weather and road condition information systems. First of all, it is important to simplify the user interface facilitating one access point for the user by an integration of the different sources and systems. As shortly explained in the chapter 1 Introduction the normal road user (traveller) has today at least three different interfaces to collect the required information. The specification, design and implementation of such systems should be based on international standards and best practice as described by the Nordic road authorities having already implemented this type of systems.

Variable speed limits

The implementation of such systems are expected to have the following impacts:

- A reduction in the accident rate and costs as experienced by other road authorities having implemented VSL on motorways
- Speed reduction as the drivers comply better to the dynamic speed limits than the static speed limits.
- More smooth driving and less differences in the speed selected by the different types of drivers which again causes less sudden breaking and a more environmental friendly driving

Recommendation

We recommend that the Norwegian Public Roads Administration starts the process of developing a Norwegian guideline for the implementation of variable speed limits (VSL) on motorways with high speeds in line with the best practice and recommendations as described by the EasyWay project [19] taking into account the data collected and analysed at E18 in Vestfold. Further it should remove the existing barriers in the existing guidelines on variable message signs that prevents the implementation of VSL as described in Chapter 8 Norwegian guidelines regarding introduction of weather-controlled VSL.

The implementation of VSL requires reliable data from sensors and this should be reflected in the guidelines requirements on reliability, availability and accuracy of the information collected and used for varying the speed limits.

The guidelines should cover the following aspects:

- The authorisation to use variable speed limits due to weather and road conditions
- The prerequisites that should be fulfilled concerning
  - parameters that should be used for an automatic and/or manual selection of variable speed limits
  - parameter limits and the algorithm used for an automatic and/or manual selection of variable speed limits
  - Reliability, availability and accuracy of the information collected and used for varying the speed limits
  - The minimum period of time that a speed limit should be shown
  - The minimum length of road section that should be subject to a decreased/increased speed limit
  - Verification of the weather and road conditions before a speed limit is changed
- The choice between automatic and manual control for the different speed limits
- The speed steps to be used when changing the speed limits: 10 and/or 20 km/h
- The maximum distance between the variable speed limits signs
- The information signs (variable message signs) to accompany and explain the reason for the reduced/increased speed limit
- The monitoring of the variable speed limit signs and the logging of the speeds shown
- The enforcement of variable speed limits

12 Further Research and development activities

The following R&D activities seems required in relation to the implementation of the two ITS services 1) To inform travellers about weather and road conditions and 2) To reduce the speed limit due to weather and road conditions:

- A more detailed study of the data quality provided by the different types of sensors to ensure that the data collected could be used as parameters in an algorithm for messages to the road users both concerning weather and road conditions and variable speed limits
- A more detailed study of the relationships between the speeds the drivers prefer and the real road and weather conditions, e.g. with data from other road stations than the ones along E18 in Vestfold
- The development of an algorithm that supports the generation of messages to the road users about the weather and road conditions
- The development of an algorithm that supports the reduction of speed limits in line with the weather and road conditions
- The relationships and interactions between the two algorithms
- The prerequisites and functional and technical requirements for a system including all ITS sub-systems for weather and road condition information
- The prerequisites and functional and technical requirements for a system including all ITS sub-systems for variable speed limits
- The interaction and relationships between the two systems (the systems could sometimes be autonomous and they could sometimes be cooperative)
- The roles and responsibilities involved in the operation of the two systems, either individually or in cooperation
- The integration of data from external systems, e.g. The Norwegian Meteorological Institute, used as input to the algorithms and for possible prognoses that could be part of the control strategy for both weather and road conditions and variable speed limits
- Enforcement strategies and measures

13 References

Ref. no.	Full title
[1]	EasyWay, (2012) Traveller Information Services – Weather information
[2]	Pilli-Sihvola, Y. et al., (2014) RWIS in Finland 2014
[3]	http://www2.liikennevirasto.fi/alk/english/
[4]	http://sv.ilmatieteenlaitos.fi/
[5]	Holmström, M. (2014), Open data based RWIS for mobile devices
[6]	http://www.infotripla.fi/digitraffic/doku.php?id=start_en
[7]	www.vintertrafik.dk
[8]	Trafikken.dk
[9]	www.vejvejr.dk
[10]	Petersen, C. et al, 2012, Fine-Scale Road Stretch Forecasting (DMI)
[11]	Sigurdsson, S. (2004) Flow and presentation of road weather data and winter maintenance activities on the Internet, 12th SIRWEC Conference in Bingen, Germany, 2004
[12]	Vinterman as presented on www.viabilite-hivernale.equipement.gouv.fr/IMG/pdf/VINTERMAN-folder_cle1ea443.pdf
[13]	www.trafikinfo.trafikverket.se/LIT/#url=Vagtrafiken/English
[14]	Abdi, a: et al, (2012) Use of Road weather information systems (RWIS) as assistive Tool for Effective winter road maintenance – technical and contractual interactions
[15]	Seidl, W and Cypra, T. (2012) Maintenance Decision Support System (MDSS) ASFINAG/Austria – Experience of a Comprehensive Winter Maintenance Management System. Chapter in Data and Mobility. Volume 81 of the series Advances in Intelligent and Soft Computing pp 139-150.
[16]	EN 15518 – a European Standard for Road Weather Information Systems (RWIS)
[17]	www.asfinag.at
[18]	EN 15518-1:2011 Winter maintenance equipment – Road weather information systems – Part: Global definition and components
[19]	EasyWay Harmonising European ITS Services and actions. TMS-DG02, Version December 2015. Traffic Management Services. Variable Speed Limits. Deployment guideline.
[20]	EasyWay VIKING 2007-2012, Overview of ITS evaluations 2007-2012, Version: 1.0, Date: October 2013
[21]	Rämä, P, Schirokoff, A., Luoma, J., 2004. Practice and deployment of variable message signs (VMS) in Viking countries – potential for harmonisation. FINNRA internal report 34/2004.
[22]	FHWA-SA-12-022. 2012. Guidelines for the Use of Variable Speed Limit Systems in Wet Weather.
[23]	Pilli-Sihvola, Y., 2014. Variable speed limits and info signs in Finland 2014.
[24]	U.S. Department of Transportation. Office of the Assistant secretary for Research and Technology. Benefits Database. A review of ITS in Europe. August 1999.
[25]	Stoelhorst, H., 2011. Summary results of Dutch Fields Trials with Dynamic Speed Limits. Dynamax project. ITS Orlando, TS 100 – paper 2248.
[26]	Rämä, P., 2001. Effects of Weather-controlled variable message signing on driver behaviour. Aalto University. ISBN 951-38-5872-3.
[27]	Al-Kaisy, A., Ewan, L. and Veneziano D. (2012). Evaluation of a Variable Speed Limit System for Wet and Extreme Weather Conditions: Phase 1 Report. FHWA-OR-RD-12-14.
[28]	Statens vegvesen (2016) Håndbok N200 Vegbygging (Guideline N200 Road building)
[29]	Lind, G., (2009?), Weather and Traffic controlled variable speed limits in Sweden
[30]	Arnesen, P., (2016), Mulighetsstudie for førevarsling – data fra værstasjoner, SINTEF memo (In Norwegian only)

[31]	Norwegian Public Roads Administration, (2014), Håndbok V321 Variable trafikkskilt (Guidelines V321 Variable traffic signs) In Norwegian only.
[32]	http://www.road.is/
[33]	B. Ólafsson, 2002, Road weather information for customers - Iceland Proceedings of the 11th SIRWEC Conference, Sapporo, Japan (26-28th January 2002)
[34]	www.vegvesen.no/vegkart
[35]	Mikalsen, S., 2014, Vær på veg 2014

Annex A – H: Descriptions of national Road and Weather Information systems

A Finland

Name of the application (if used)
Road Weather Information system (RWIS) in Finland. The application provides data for the whole main road network in Finland.
Information sources:
The following references have been used: [1], [2], [3], [4], [5] and [6].
Physical architecture

The Finish RWIS physical architecture is shown in **Error! Reference source not found.**.

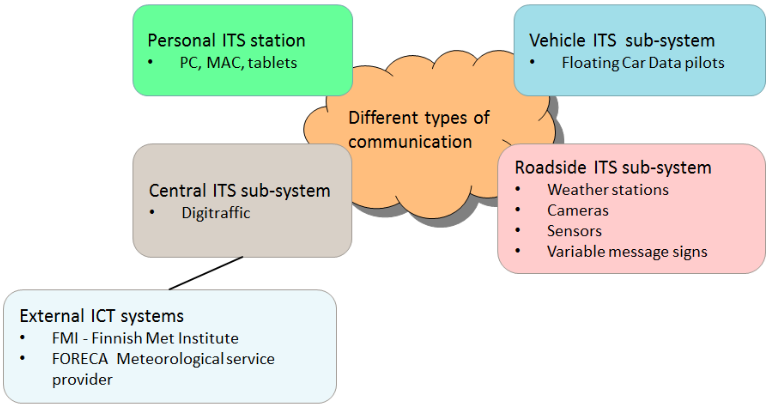


Figure 27 The RWIS in Finland

The **Personal ITS station** is so far limited to the Transport User PC/MAC or tablet with web browsers. However, there is an ongoing project to also to deliver the ITS service to other mobile platforms, e.g. smartphones [5].

The **Central ITS sub-system** consists of a central server for information collection and information management. The central server is connected to two external central systems, one providing radar and satellites images and one providing road weather forecasts. The first system is operated by FMI, the Finnish Met Institute and the second one is operated by the FORECA, Meteorological service provider. The Central ITS sub-system is called Digitraffic with the subtitle Open Traffic Data [6]. Digitraffic is a service offering real time information and data about the traffic, weather and condition information on the Finnish main roads. The service is provided by the Finnish Transport Agency.

The **Roadside ITS subsystems** consists of the following equipment:

- Road weather stations, 614 units on 370 sites
- Optical stations, 154 units that measures the road condition (friction) remotely
- Traffic monitoring stations, 450 units and services
- Road condition cameras, 556 units plus some additional monitoring cameras in tunnels
- Variable message signs, 400 km, 1500 signs

There are also several 'mobile' Roadside ITS sub-system, i.e. friction sensors mounted on vehicles or trailers in operation. These are used for both collecting information on road friction but they are also used to collect data on the accuracy and reliability of various friction meters so that new friction meters could be introduced in the quality control of highway winter maintenance.

The **Vehicle ITS sub-system** includes several pilots for Floating Car Data (FCD) like:

- Traffic information using Bluetooth and cellular network information
- Road weather information (CoMoSeF - Cooperative Mobility Services of the Future)
- FCD pilot, 150 vehicles
- VTT, information from Helsinki busses

Functional architecture

Weather and road conditions information collection:

The information from all the Roadside ITS sub-systems, Vehicle ITS sub-systems and from the FMI and FORECA central systems are collected by the Central ITS sub-system, i.e. Digitraffic. Radar and satellite images are collected from FMI and Road weather forecasts are collected from FORECA [2]. From the Roadside ITS sub-systems the following information is collected [3]:

- Weather information: Current temperatures of air, road surface and ground, precipitation, dew point, wind speed and direction, humidity, visibility,
- Road condition: Friction, surface moisture, salt concentration, water amount, snow amount, ice amount.
- Traffic flow conditions: latest 5 minute median, corresponding average speed, traffic volume in both directions and average speed in both directions.

In addition the Roadside ITS sub-systems provides pictures that show both the road conditions and the traffic conditions.

The information is managed and processed by the Finnish Transport Agency.

Information fusion and processing

Data are collected and processed by the FTA's data center. Digitraffic is a service offering real time information and data about the traffic, weather and condition information on the Finnish main roads. The service is provided by the Finnish Transport Agency, and it is addressed for organisations (ProDigitraffic) and individual persons (OpenDigitraffic). The road traffic part of Digitraffic was planned to be renewed in Autumn 2015. The purpose of the renewal is to close down the old Pro Digitraffic service and bring the whole API under the digitraffic.fi domain name. [6]

Weather and road conditions distribution to Transport users

The information collected and processed by the Digitraffic is distributed via different kinds of channels:

- To the road infrastructure users via the web service, e.g. as presented at http://liikennetilanne.liikennevirasto.fi/
- To the contractors for winter maintenance by the services provided by the three road weather centres: Destia, Suomen Kelitieto and YIT
- To End user service providers, e.g. radio and TV
- To Traffic Control Centres that uses the information for variable message signs distributing information about road and weather conditions and variable speed limits

Roles, responsibilities and actors
The roles called ***Road Network Operator*** and ***Traffic Manager*** presented in the role and responsibility model in 3.4 are fulfilled by the Finnish Transport Agency (FTA) who is responsible for Finnish roads, railways and waterways and for the overall development of Finland's transport system. FTA promotes an effective transport system, traffic safety and a sustainable development of the regions. FTA is an expert organisation specialising in transport that operates under the jurisdiction of the Ministry of Transport and Communications and employ approx. 650 professionals. Their tasks vary from expertise in the transport field to operative traffic control and administration. The role ***Transport user*** also presented in the role and responsibility model in 3.4 is fulfilled by the drivers using the Finish road infrastructure and the contractors providing maintenance services. The role ***Service Provider*** is fulfilled by several actors. The Finnish Met Institute, The Meteorological service provider, End user service providers and online road- and weather condition providers are the main actors.
Objectives and evaluations
The objectives of the RWIS are according to [1] to Increase road safety and Increase traveller convenience.
Any other relevant information
In [1] the ITS service provided by FTA is described as follows: *FTA provides current road weather and a 6 hour forecast for main roads, road weather station information and road weather camera pictures, and traffic warnings issued as a result of poor road weather conditions. The 24 hour road weather forecast is provided in co-operation with The Finnish Meteorological Institute (FMI).* *Thematic coverage:* • *Weather information: Current temperatures of air and road surface, precipitation (no rain, moderate, light, rain etc.) and road condition (dry, moist, wet, icy etc.). Road weather camera pictures are also available of the road sections.* • *The road weather forecast for the next 6 hours: Driving conditions are divided into three levels; normal, bad and very bad, and each level has its own colour symbol. Information is presented on a map which is coloured according to these symbolic colours. Information on precipitation and temperature on road surface at a specific point on the road is also available.* *Data quality:* Forecasting information available for up to 6 h (FTA) and 24h in advance (FMI). The forecast for the next 6 hours and warnings are available from the 1st of October to the 30th of April The picture below shows an example on the road and weather condition provided by the FTA [3]. The weather conditions are shown on the right side of the picture for the selected road link in the middle of the picture (red line with dashes between two camera points). A picture from one of the monitoring cameras is also shown. The legend of the colour of the road links are explained in the right part of figure 10.

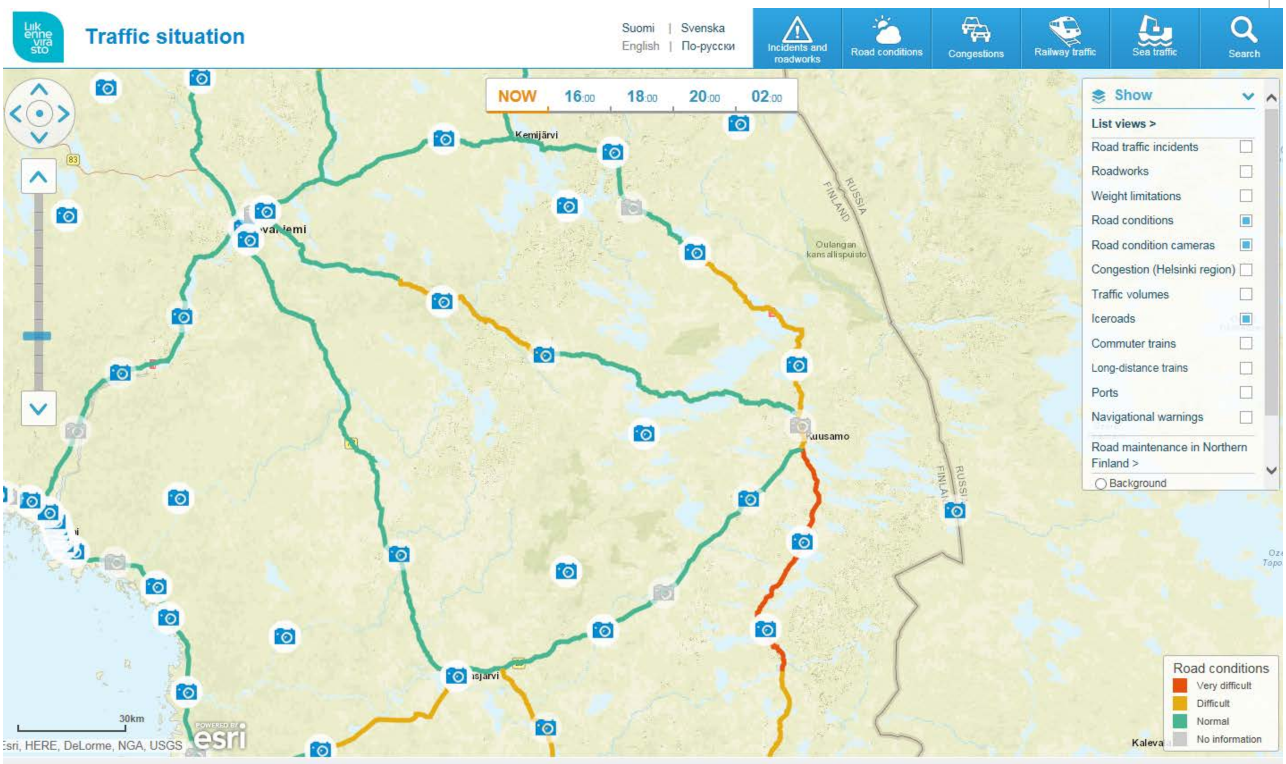


Figure 28 Example on the RWIS web service

B Denmark

Name of the application (if used)
Vintertrafik (both web based and smartphone app) and Trafikken. The ITS service Vintertrafik (Winter traffic) is operated during winter time and is focusing on information related to winter conditions which is relevant for this feasibility study on weather controlled Variable speed limits. Hence, the focus on the Danish use case is more on the Vintertrafik application than the Trafikken application which includes more general information about the traffic flows, road works etc. The Vejvejr service (Road weather) is an important platform for the Vintertrafik service.
Information sources:
The following references have been used: [1], [7], [8], [9], [10], [11] and [12]
Physical architecture
Figure 29 shows the physical architecture of the Danish Weather Information System.

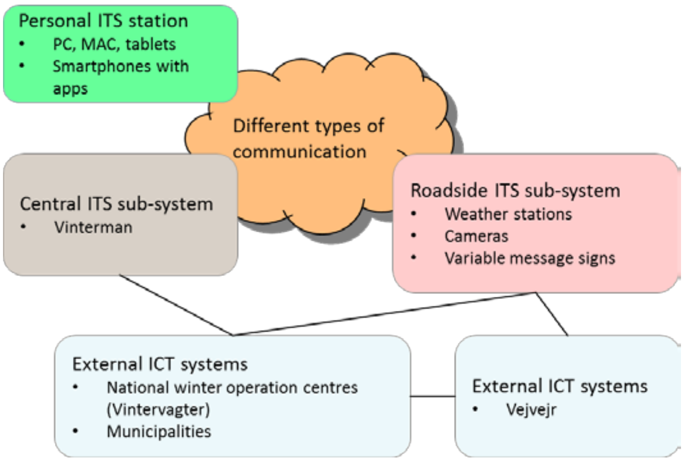


Figure 29 The RWIS in Denmark

The **Personal ITS station** includes the transport user PC, MAC, tablets with the web service Vintertrafik.de and smartphones with the Vintertrafik app and SMS services.

The **Central ITS sub-system** is the Vinterman server for information collection and handling. The Vinterman server is connected to the National winter operation centres and the municipalities. The Vinterman server receives messages from the National winter operation centres and the municipalities and the information is then distributed to the transport users via different media, e.g. Vintertrafik.dk and the Vintertrafik app.

The external ICT system Vejvejr operated by the Danish Meteorological Institute (DMI) plays an important role in this architecture.

The **Roadside ITS sub-systems** consists of the following equipment

- 380 road weather stations
- About 100 web cameras showing the road and traffic conditions
- Variable message signs

There are also several 'mobile' roadside ITS sub-system providing road weather information. These are patrol vehicles that are capable of measuring air and road surface temperature, air humidity, remaining salt on the road surface etc.

Functional architecture

Weather and road conditions information collection:
The information available at the road weather stations, the web cameras, the Vejvejr service and local observations are collected and handled by the Vintertrafik operators. The information from the road weather stations are updated every 5 minutes and includes information about air and road temperature, air humidity, road condition (dry, wet, salted, snow, ice and frost), wind speed and direction precipitation (form and amount) and visibility. Other types of information provided by the Vejvejr is cloudiness (satellite pictures), precipitation (radar pictures) and weather forecasts that are updated each hour.

Information fusion and processing:
The information collected by the operators are processed and the result is presented as a message to the Vinterman server.

Weather and road conditions distribution to Transport users:
The Vinterman server distributes the message with the information from the Vintertrafik operator to the Traffic Information Centre (TIC) and to the Vintertrafik.dk. On the web service Vintertrafik.dk the message is presented partly as text and partly in graphics, e.g. different colours for the road condition for the different links in the road network. At the TIC the message is interpreted by the operators and the information is distributed via different media, e.g. radio and TV.

The picture below shows an example on how the messages from the Vintertrafik server are presented at Vintertrafik.dk. The area shown is part of the area around Aalborg (south of Aalborg). The red road links have icy road surface. The road surface temperatures vary between 0 and 5 degrees and there is a slippery road warning in the area with red road links. By tapping the cameras icons the latest picture from the actual web camera will be shown in a pop-up window.

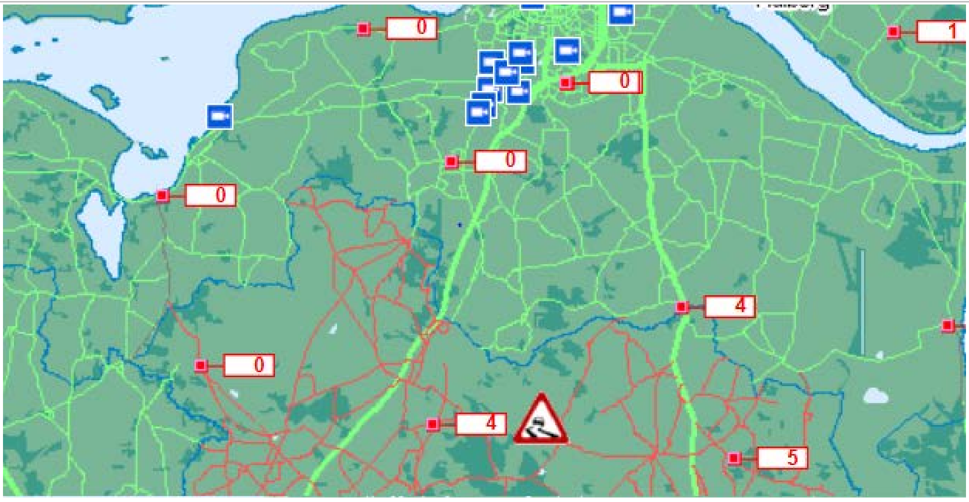


Figure 30 Part of the Vintertrafik.dk web service picture for the Aalborg

Roles, responsibilities and actors
The role called ***Road Network operator*** is fulfilled by the Danish Road Directorate for the national road, the County administration in the 13 counties for the regional roads and the 271 municipalities for the local roads. The role called ***Traffic manager*** is fulfilled by the Road Directorate through its operation of the Vintertrafik system. The municipalities are also involved in the operation. The ***Transport users***, i.e. the users of the information provided by Vintertrafik, are the personnel at the winter surveillance centres, the TIC, municipalities, media people and local contractors for salting and snow removal. The role ***Service Provider*** is fulfilled by several actors. The Danish Met Institute, End user service providers and online road- and weather condition providers are the main actors.
Objectives and evaluations
The objectives of the Vintertrafikk are according to [1] to increase road safety and traveller convenience.
Any other relevant information
The Vejvejr application requires the user to enter into a subscription contract with the Danish Road Directorate. Variable message signs for road condition and warnings are used only one place. The signs are close to a bridge made of steel and the road surface on the bridge may be different from the adjacent road sections. The VMS are automatically activated based on information from road sensors.

C Sweden

Name of the application (if used)
Läget i trafiken (Traffic conditions) - web services for PC, Mac, tablets and smartphones
Information sources:
The following references have been used: [1], [13] and [14]
Physical architecture

Figure 31 shows the physical architecture of the Swedish Weather Information System.

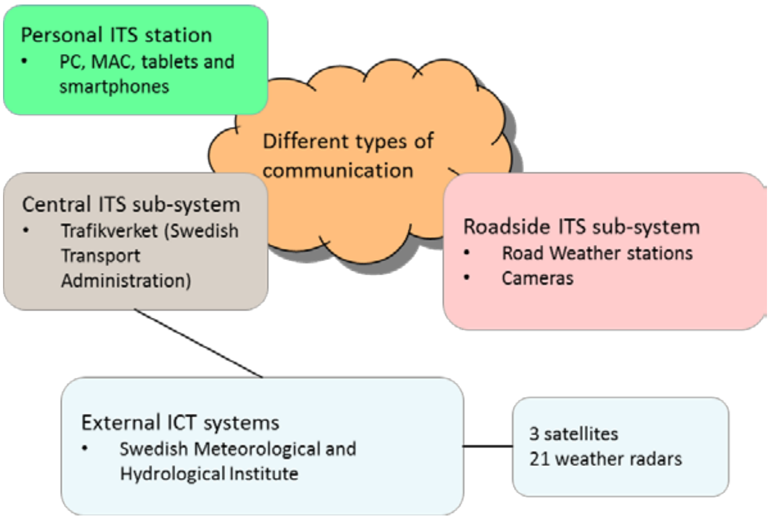


Figure 31 The RWIS in Sweden

The **Personal ITS station** includes the transport user PC, MAC, tablets and smartphones with the web service Läget i trafiken. So far there are no apps for the smartphones but the application has a mobile interface for those using their smartphones for accessing the application.

The **Central ITS sub-system** is the Swedish Transport Administration (STA) server for information collection and handling. The server is connected to the Swedish Meteorological and Hydrological Institute (SMHI). Also information from the winter maintenance personnel is used for the processing of information.

The **Roadside ITS sub-systems** consists of the following equipment

- Approximately 780 road weather stations
- About 200 web cameras showing the road conditions

There is no information available indicating whether the Roadside ITS station includes variable messages signs to inform the users about the road and weather conditions.

Functional architecture

<u>Weather and road conditions information collection:</u>
The information available at the road weather stations, the web cameras, the information from SMHI and local observations done by the winter maintenance personnel are collected and handled by the STA server for the Läget i trafiken application. The information from the road weather stations are updated every 30 minutes.

<u>Information fusion and processing:</u>
The information collected is processed by the STA server.

<u>Weather and road conditions distribution to Transport users:</u>
The information provided to the public and transport users is regarding wind speed and direction, precipitation, air and road surface temperature, road condition (dry, wet, ice, snow and slush). The distribution is done by the web service Läget i trafiken both by interface to PC/Mac/tablets and a web interface to smartphones.

Error! Reference source not found. below shows an example on how the information is presented at trafikinfo.trafikverket.se/LIT/#url=Vagtrafiken/English. The area shown is in the middle part of Sweden. The picture was collected at the end of January 2015 and shows that only a few sections of the main road E4 have no problems reported. The rest of the roads have either snow and ice, difficult road conditions or risk for difficult road conditions.

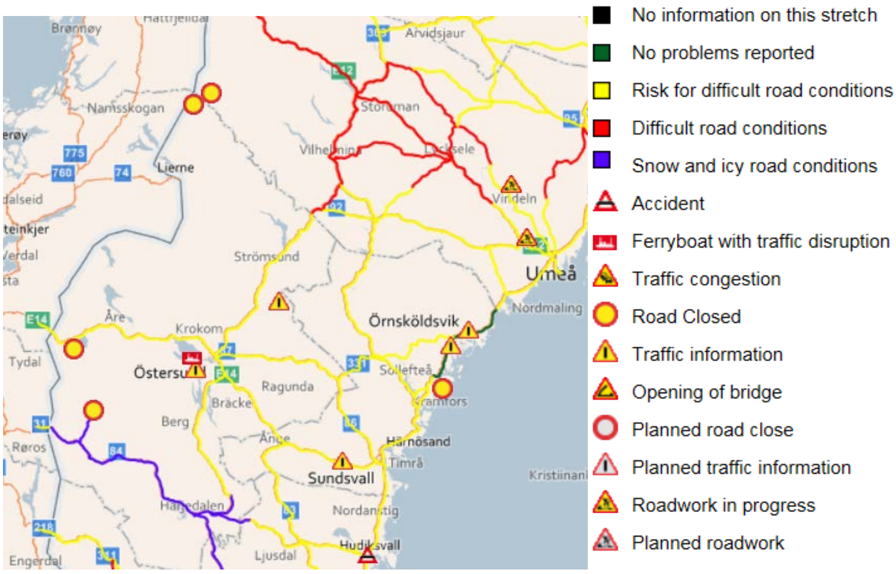


Figure 32 Road condition as presented by the RWIS in Sweden

It is also possible to see the temperatures, wind direction and speed and the type of precipitation by selecting different categories of information to be shown in the map. The user also has access to road condition cameras as shown in **Error! Reference source not found.** with some additional information. The picture shows that the road surface is partly covered with snow, the road surface temperature is -1.5 °C, the air temperature is -0.4 °C, it is snowing and the wind speed is 6 m/s.

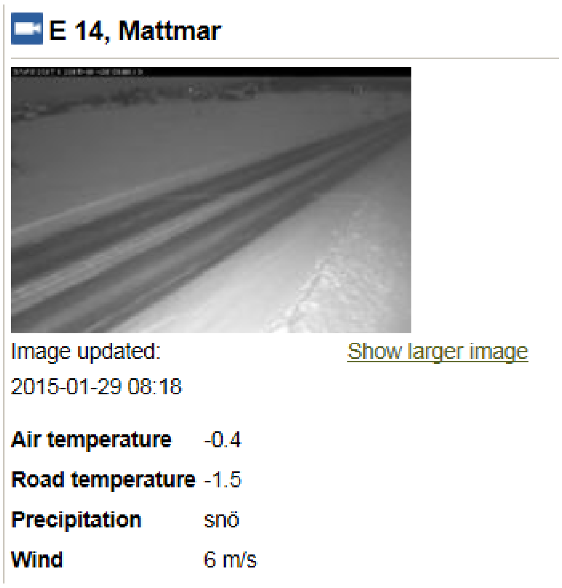


Figure 33 Road condition camera at E 14 Mattmar

Roles, responsibilities and actors

The role called ***Road Network operator*** are fulfilled by the Swedish Transport Administration (Trafikverket) for the national roads, the County administration for the regional roads and the municipalities for the local roads.

The role called ***Traffic manager*** is fulfilled by the Swedish Transport Administration through its provision of the ITS service Läget i trafiken (Traffic conditions).

The ***Transport users***, i.e. the users of the information provided by Läget i trafiken, are the drivers (road users), local contractors for salting and snow removal and media for public information on road and weather conditions.

The role ***Service Provider*** is fulfilled by several actors but the Swedish Meteorological and Hydrological Institute (SMHI) is probably the main actor.

Objectives and evaluations

According to [1] the objectives are increase of safety and increase travelers' convenience.

Any other relevant information

The STA also provides a map showing the prognoses for different types of slippery road surfaces. The map is found on www.trafikverket.se (in Swedish only) and an example is shown in **Error! Reference source not found.**. The red parts shows general or local slippery roads due to ice, the blue parts shows general and local slippery roads due to cold weather and high humidity and the yellow parts shows general and local slippery roads due to snow.

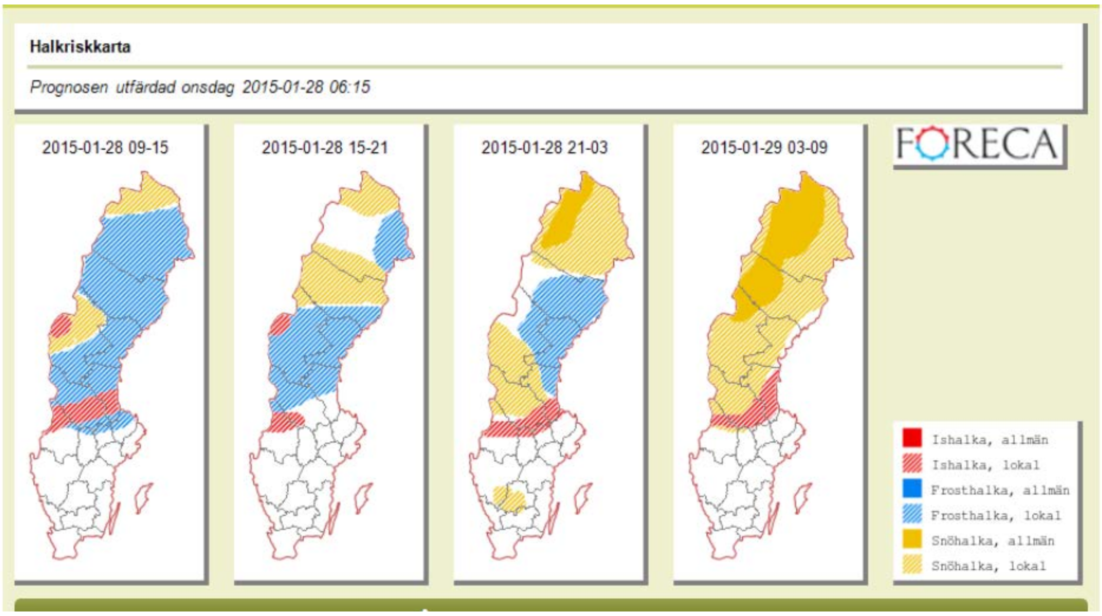


Figure 34 24 hours prognoses for slippery roads

D Iceland

Name of the application (if used)
Færð og aðstæður (Road Conditions and Weather in English). The application provides data for the whole main road network in Iceland.
Information sources:
The following references have been used: [32] and [33]. *Only [32] and [33] has been used for the collection on the information. The last reference is from 2002 and things may have changed since then, e.g. equipment used at the Roadside weather stations. This implies that the Icelandic Road weather system has not been described to the same level of details as most other countries.*

Physical architecture

The Icelandic RWIS physical architecture is shown in Figure 35 .

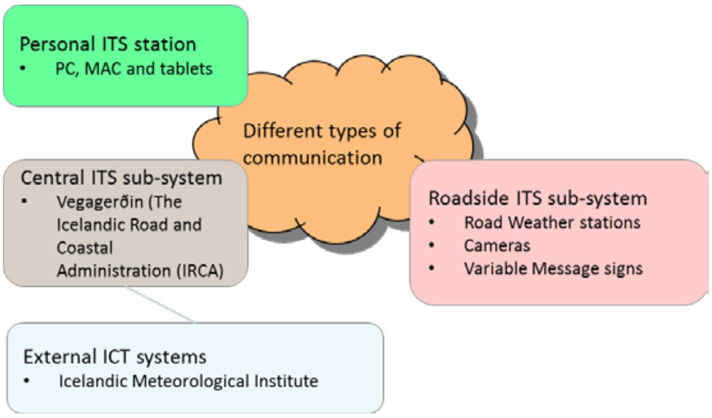


Figure 35 The RWIS in Iceland

The **Personal ITS station** is so far limited to the Transport User PC/MAC or tablet with web browsers.

The **Central ITS sub-system** consists of a central server for information collection and information management operated by The Icelandic Road and Coastal Administration (IRCA). The central server is connected to the Icelandic Meteorological Institute (IMI) that provides information on weather forecasts, icing forecast, satellite images and weather radar data [33].

The **Roadside ITS subsystems** consists of the following equipment:

- Road weather stations
- Road condition cameras
- Variable message signs

Functional architecture

Weather and road conditions information collection:
The information from all the Roadside ITS sub-systems and from the IMI are collected by the Central ITS sub-system operated by IRCA. The Roadside ITS sub-systems the following information is collected [33]:

- Weather information: Current temperatures of air, road surface, precipitation, wind speed and direction and humidity.
- Road condition: Frost in road, icing

In addition the Roadside ITS sub-systems provides pictures that show both the road conditions and the traffic conditions.

The information is managed and processed by the IRCA.

Information fusion and processing
Data are collected and processed by the IRCA data center.

Weather and road conditions distribution to Transport users

The information collected and processed by the IRCA is distributed via different kinds of channels [33]:

- To the road infrastructure users via the web service, e.g. as presented at www.road.is and by variable message signs
- To the IRCA as operational information for supporting the planning and execution of the maintenance and service work carried out by ICRA and contractors
- To End user service providers, e.g. radio and TV
- To Traffic Control Centres that uses the information for variable message signs distributing information about road and weather conditions and variable speed limits

Roles, responsibilities and actors

The roles called ***Road Network Operator*** and ***Traffic Manager*** presented in the role and responsibility model in 3.4 are fulfilled by the Icelandic Road and Coastal Administration (ICRA) who is responsible for about 13.000 km. of main roads and country side roads in Iceland. This includes planning, design, construction, maintenance and service of those roads. IRCA is also responsible for ferry operations which are all outsourced to ferry companies.

The role ***Transport user*** also presented in the role and responsibility model in 3.4 is fulfilled by the drivers using the Icelandic road infrastructure and the contractors providing maintenance services.

The role ***Service Provider*** is fulfilled by several actors. The Icelandic Met Institute and End user service providers are the main actors.

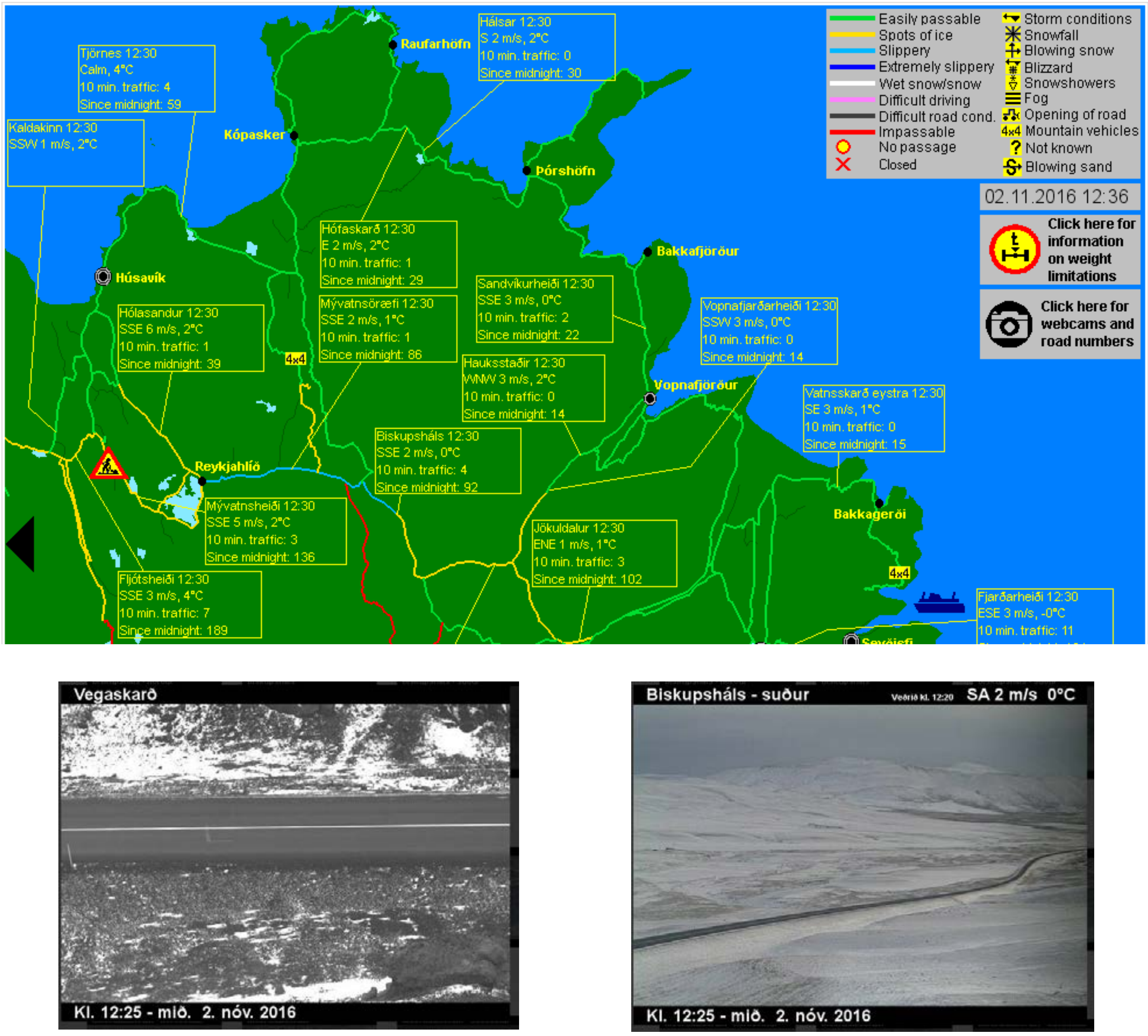
Objectives and evaluations

The main objective of the RWIS is according to [33] summarised in the following:

Communications in Iceland are dependent upon the weather conditions; hence it is important for the Icelanders and other nations living in similar circumstances that information about the weather, the development of the weather, and the conditions in the public communication system being as correct and good as possible in order to ensure the safety of commuters. The Icelandic Public Roads Administration has thus strongly focused on this factor in its prioritization of projects.

The Public Road Administration's experience from these forecasts is quite good and the service has provided PRA with important information regarding the planning of the winter road-service as the forecasts have decreased the response and preparation time for icing prevention and snow plowing. The beginning time of precipitation and pending icing conditions is now known with sufficient accuracy facilitating the launching of icing prevention measures before such conditions occur, as well as further ensuring that the snowplowing equipment is on the road before snowing begins.

The reaction by the road users is very positive. Research indicates that most road users in

Iceland utilize the information system one way or the other during their travels.
Any other relevant information
Some examples on road user web interface is shown in **Error! Reference source not found.**.  Figure 36 Example on the Icelandic RWIS web service

E Austria

Name of the application (if used)
Unterwegs (On the way) – webservice and smartphone app operated by ASFINAG (owned by the Austrian Federal Government).
Information sources:
The following references have been used: [1], [15], [16], [17]
Physical architecture

Figure 37 shows the physical architecture of the ASFINAG Weather Information System.

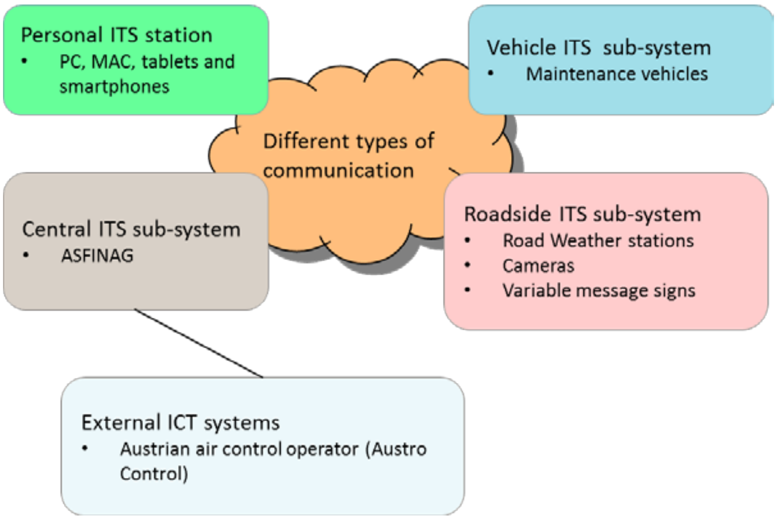


Figure 37 ASFINAG Weather Information System

The **Personal ITS station** includes the transport user PC, MAC, tablets and smartphone.

Traffic Information Austria is a route planner for all modes of transport and covers all of Austria. It provides the transport users with information "*about everything that's happening on the roads*" in real time at www.asfinag.at/routenplaner. Commuters and users of modern operating systems such as Microsoft Windows or Mac OS x can access ASFINAG traffic information as a mini app or gadget direct from their desktop. The advantages are the access to over 580 webcams and the user can store webcams as favourites and synchronise these with other devices (like smartphones).

This information is accessible using a smartphone (iOS, android and Windows Phone or Blackberry 10) with the free ASFINAG "Unterwegs" traffic app. The app keeps users updated on the latest traffic situation, shows where the ASFINAG rest facilities are and provides access to over 580 webcams. Users can also access traffic information with a TMCplus-enabled navigation device (TMC means here Traffic Message Channel). Overhead signs on the motorways and expressways also provide information about the latest traffic situation. It is also available from the ASFINAG homepage (www.asfinag.at) as a special TV app for Samsung SmartTVs (Samsung, LG and Philips). In addition, TV partners (such as Puls4) also show selected ASFINAG camera images on breakfast television.

The **Central ITS sub-system** is the National ASFINAG Traffic Control Centre in Vienna-Inzersdorf for information collection and RWIS data handling. ASFINAG has also 8 regional traffic management centres and 43 motorway operation and maintenance centres. Central requirement for the Traffic Monitoring System is to technically monitor all facilities and systems within ASFINAG's telematics infrastructure as well as to support maintenance work. The system consists of three core elements:

- Process controlling: Displaying incidents on connected facilities and systems and their processing status
- Process management: Troubleshooting and maintenance is supported and documented
- Contract management: Contract details of maintenance providers are allocated and processed

The **Roadside ITS sub-system** consists of the following equipment:

- 6 Toll stations
- Road weather stations
- Traffic management systems
- Approx. 580 web cameras
- Approx. 880 electronic displays
- Fixed automated spray technology (FAST)

The **Vehicle ITS sub-system:** The winter service vehicles collect winter related data.

Functional architecture

Weather and road conditions information collection:

In the last few years, ASFINAG has decided to launch a specific company-wide project: The Maintenance Decision Support System (MDSS) ASFINAG. The MDSS is a modular and scalable platform able to support the decisions of all the maintenance depots within the two service companies of ASFINAG [15].

The winter service concept has evolved from the use of weather forecast reports received once a day by fax, local measurement data from ice warning/RWIS systems with stations, manual recording of interventions, to the use of a fully integrated solution with a set of specific features: the MDSS.

The new features of the software are, on the one hand the intelligent linking of weather information and periodic road condition data from RWIS stations, providing predictions for road sections. On the other hand, a management system providing to users situation maps, e.g. RWIS data, visualized road condition prognoses, activities and locations of winter service vehicles.

Weather and road condition information collection is represented in**Error! Reference source not found.**Figure 38.

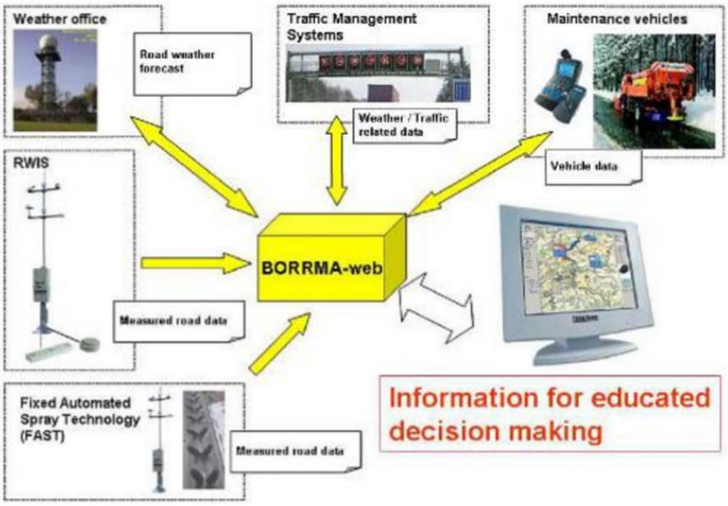


Figure 38 Functional principles of the Boschung Road and Runway Management System.

<u>Information fusion and processing:</u>

The information from all the Roadside and Vehicle ITS sub-systems are collected by the Central system. From the listed sub-systems, the following information is collected:

- RWIS and FAST: Measured road data
- Traffic Management Systems: Weather/Traffic related data
- Maintenance vehicles: Vehicle data

Risk levels are determined for time periods for each road segment and are displayed on a dynamic map. The road maintenance managers have by this way, an overview of the current status of their entire road network and using a time slider they have access to forecasted road surface states.

<u>Weather and road conditions distribution to transport users:</u>

Weather and road condition information are available to road users via the free ASFINAG app, *On the way.* The app provides the following information:

- Kompagnon BETA shows the next four event on the route. The last feature integrated Hotspots. In case of approaching delay, length and loss of time are announced.
- Live Bilder are the latest information of traffic situation with the help of 500 webcams. Webcams covering specific sections of routes can be saved as favourites. Roadwork notifications are superposed onto the camera images. Access to over 580 webcams
- Rasten: Information about Rest facilities
- Videomaut: Using the smartphone to apply for electronic toll passes.
- Verkehsrinfo: The following information is made available:
  - Traffic disruptions such as congestion and accidents
  - Roadworks
  - Road closures, tunnel safety
  - Information on mandatory use of snow chains

With an activated GPS on the smartphone, users have access to a map of traffic information for the user current location.

- GO LKW BUS: Go toll customers have access information related to their vehicles via the app.
- ASFINAG News: Information about future developments of the app.
- Vertriebsstellen: Position of sale points.

- Wichtige Rufnummern: Telephone number of the service centre.
- Melden: App users can report objects on the road, road damages, and dangerous situations.
- Feedback zur App: Feedback to the app developers.

Figure 39 below shows examples of features available with the ASFINAG On the Way app.

Figure 39 Examples of the On the way features

Roles, responsibilities and actors

The three roles called *Road Network* operator, *Traffic manager and Service provider* are fulfilled by the **ASFINAG Group** that is responsible for the planning, construction, operation and toll collection of 2,183 km of motorways and expressways in Austria. ASFINAG is a state-owned company.

The role, ***Service Provider*** is fulfilled by several actors. The main actor is the Austrian civil aviation organisation, Austro Control that is a partner for weather information. This actor review the necessary data and create the forecasts for Road Weather Information System SWIS.

The roles ***Road Network operator and Traffic manager*** is fulfilled by ASFINAG that managed 43 Motorway maintenance Centres and 9 traffic centres. One National traffic management centre, Vienna Inzersdorf, is ranked above the regional subsidiaries. The centre monitors the network 24 hours a day and constantly exchanges information. Large-scale route diversions in case of exceptional events such as natural catastrophes are coordinated by Vienna Inzersdorf. On a day-to-day basis, Inzersdorf also works with the Ö3 radio to coordinate traffic news. Furthermore, Inzersdorf monitors any transregional special/heavy load transportation projects. Eight Regional Traffic management centres monitor, maintain and coordinate tunnels and open-air roads. If an incident occurs, this information is transmitted from the region to the national management centre and third parties.

The ***Transport users,*** i.e. are drivers (road users). The ASFINAG service centre answers all questions about Austria's motorways and expressways (e.g. road safety, traffic information, winter maintenance, toll, road construction projects, service stations, noise control and telematics).

The roles ***Transport users and Contractor*** are fulfilled by the local road maintenance contractors.

Objectives and evaluations

The objective of ASFINAG is to provide safe 2,200 km of motorways and expressways.

Any other relevant information

SINTEF

Interesting to follow the development of the Maintenance Decision Support System of ASFINAG.

F Germany

Name of the application (if used)
SWIS – Road Weather Information system (GBG SWIS – Wetterinformationssystem für das Straβenwesen. Weather information web-based: www.dwd.de/swis. DWD WarnWetter-App (iOS und Android)
Information sources:
The following references have been used: [1]
Physical architecture

Figure 40 shows the physical architecture of the German Road Weather Information System.

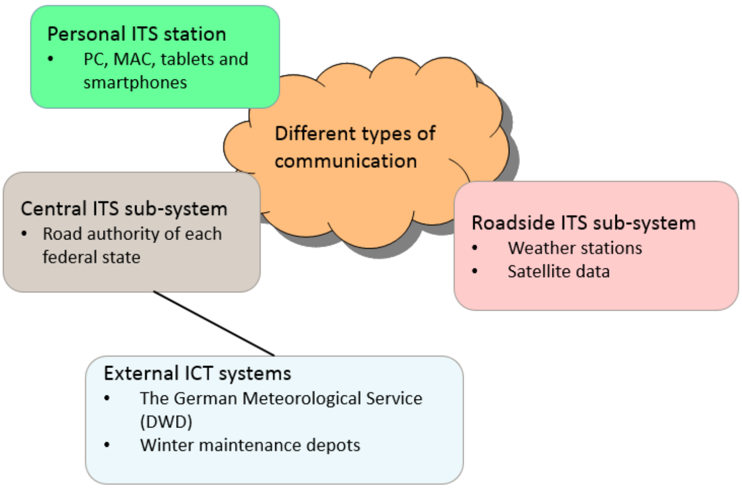


Figure 40 The RWIS in Germany

The **central ITS sub-system** is the central servers managed by the road authority of each federal state. The Germany's National Meteorological Service, Deutscher Wetterdienst (DWD), is a public institution with partial legal capacity under the Federal Ministry of Transport and Digital Infrastructure. DWD releases and publishes weather information and warning bulletins to customers and the general public on regular basis and depending on the weather situation.

The **Personal ITS station** includes the transport user's PC, MAC, and tablets.

The **Roadside ITS sub-systems** consists of the following equipment:
Around 750 road weather stations, located at selected points on the federal motorway network, collect the following data:

- Air temperature and humidity
- Wind speed and direction (at a few measuring points only)
- Precipitation, snow depth
- Roadway surface temperature and condition
- Temperature at a depth of 30 cm (at a few measuring points only) (Roadway ground temperature)

These data are available to the related motorway maintenance depots online via the telecommunications network of the federal motorways.

Functional architecture

Weather and road conditions information collection:

Thematic coverage:

- Road condition service: air temperature, relative humidity, dew point, precipitation, road surface temperature, road surface humidity, water film thickness, residual salt-factor, freezing temperature, deep level ground temperature (30 cm), (partly) Wind speed and direction
- Weather information/ prediction: cloudless, cloudy, rain, snow
- Official weather warning (3 levels each based on probability): Heavy rain, thunderstorm, storm, hail, sleekness, fog/ other reduced visibility, snow
- Forecasting information available for up to 24h in advance, less detailed forecast for the next 10 days.

Information fusion and processing:

The German Meteorological Computing Centre (DMRZ) receives global observation data and forecast fields. The current number of incoming reports is currently about one million weather reports per day. The main tasks of the DMRZ cover the operational and time-critical weather forecasting, supervision of the making of meteorological products and the global data exchange. The DWD transmits the information electronically, by files as text or table using ASCII characters, to the central computer of the Road Condition and Weather Information System (SWIS) of the road authority of each federal state. Weather data is mapped to road sections. Transmission is software-controlled, using dial-in via the public telephone network with ISDN technology. The transfer protocol is FTP to UNIX standard. One of the tasks of the SWIS is to send this information via the telecommunications cables of the federal motorways, using a special protocol, to the motorway maintenance depots. The maintenance depots of federal and state highways are not connected to the telecommunications cable and receive the information primarily from the central SWIS computer by fax via the public telephone network.

Weather and road conditions distribution to transport users and customers:

The GBG SWIS – Wetterinformationssystem für das Straβenwesen – is an online information system on road conditions based on weather and radar data. There is a closed user groups (CUG) on the internet and a subscription is required to access to data. Reports and charts (observation data, forecasts and warnings) can be ordered or subscribed by the DWD customers.

The information provided include:

- Medium-range road weather forecast (noon on the following day until noon on the third day)
- 24-hour road weather forecast, valid until noon on the following day
- Detailed road area weather forecast in three-hour blocks for the next 24 hours for narrowly defined climate areas in tabular form (clouds, precipitation, air temperature, road surface

temperature, wind direction & speed, road conditions)

- Warnings of unexpected, critical weather situations

DWD provides road weather forecasts for the federal roadways at no charge, and also to road authorities of the federal states, which construct and maintain federal trunk roads on behalf of the federal government. General and detailed road weather forecasts are otherwise available for purchase at the DWD online Weathershop.

Error! Reference source not found. shows an example of the information about the current weather provided by DWD. Prognoses are also available.

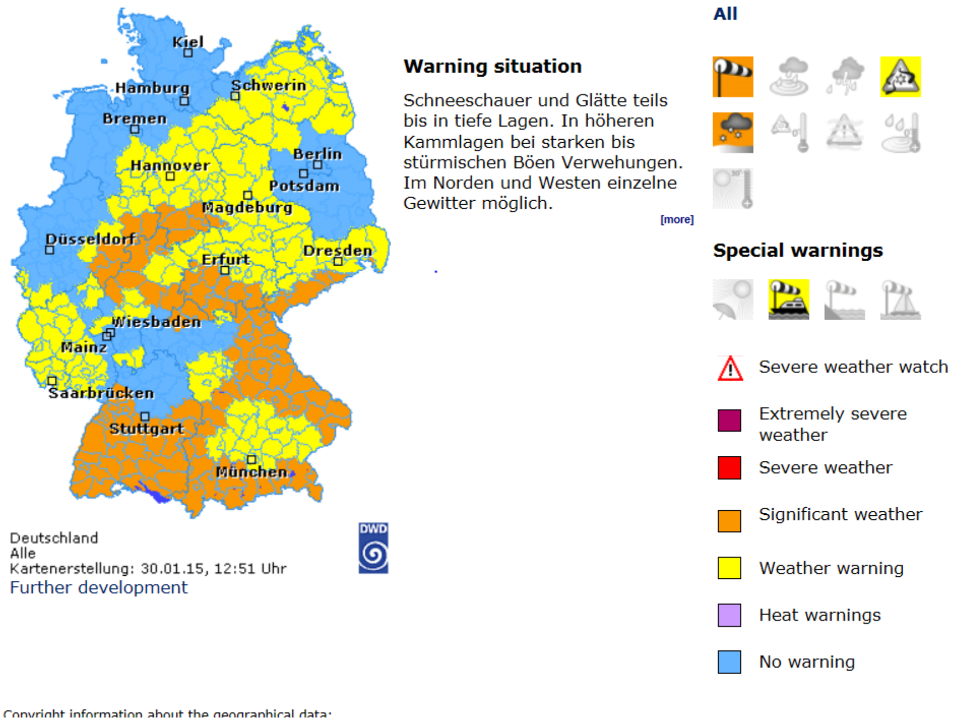


Figure 41 Weather information provided by DWD in Germany

Roles, responsibilities and actors

The Federal Ministry of Transport and Digital Infrastructure (BMVI) is divided into nine directorates-general and a total of 63 executive agencies. The Land Transport Directorate-General is responsible for all issues relating to rail and road transport.

The role, ***Service provider*** is fulfilled by DWD and some of their relevant duties are:

1. The provision of meteorological services for the general public or for individual customers and users, especially in the fields of traffic, trade and industry, agriculture and forestry, the building industry, public health, water management including preventive flood control, environmental protection, nature conservation and science,
2. the issuance of official warnings of weather occurrences that could become a danger for public safety and order, especially concerning the impending danger of floods,
3. the short- and long-term registration, monitoring and evaluation of meteorological processes, structure and composition of the atmosphere,
4. the registration of the meteorological interaction between the atmosphere and other areas of the environment,
5. the forecasting of the meteorological processes,
6. the operation of the necessary measuring and observation systems for fulfilling some of the duties,
7. and, the holding in readiness, archiving and documentation of meteorological data and products.

The role, ***Road network operator and traffic manager***, is fulfilled by the road authorities of the federal

states. The data sets (and road weather forecasts, too) are distributed via the DWD's Internet user groups and a special software, called JavaMAP3. The customers can find all observed data (road weather and DWD stations), satellite and radar images (with liquid and solid being distinguished), model forecast fields and also all text and table forecasts. Short Message Service (SMS) and fax complete the offer. A winter road maintenance information centre follows the monitoring of several parameters of the road weather monitoring stations and provides the relevant information to the different local maintenance centres, which are also linked to the SWIS network. The role, ***Transport users***, is fulfilled by the users to which the information is provided to.
Objectives and evaluations
The aim of the RWIS is to provide weather information to maintenance staff.
Any other relevant information
The application WarnWetter-App is available in Apple store or in Google Play Store. https://play.google.com/store/apps/details?id=de.dwd.warnapp

G Canada

Name of the application (if used)
Example of the province of Ontario that has the largest population. The name of the application is *Ontario.ca/511*.
Information sources:
The following references have been used: http://transcanadahighway.com/General/roads.htm http://www.mto.gov.on.ca/english/traveller/conditions/ http://www.mto.gov.on.ca/english/traveller/trip/map.shtml?ll=47.148746,-81.605468&z=6
Physical architecture

Figure 42 below shows the physical infrastructure of the Canada Weather Information System.

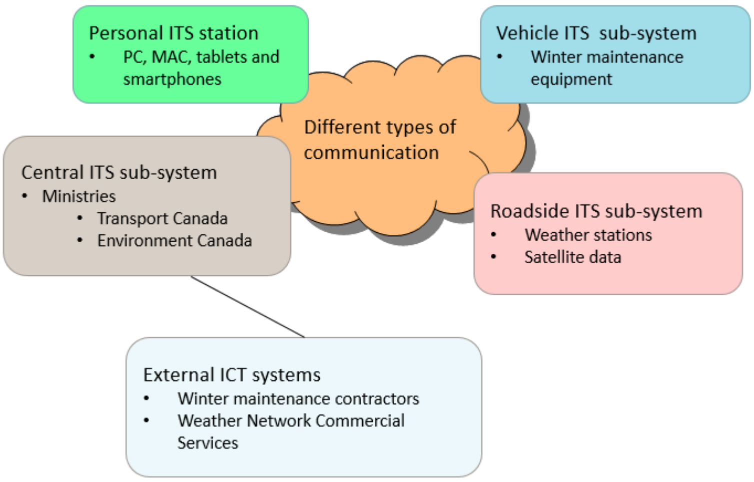


Figure 42 The RWIS in Canada

The **Personal ITS station** is the transport user PC/MAC or tablet with web browsers.

The **Central ITS sub-system** is under the responsibility of an agency for each province. For the province of Ontario, the Ontario Ministry of Transportation provides information about the winter road conditions, thanks to the *Ontario 511, traveller information services*.

The **Roadside ITS sub-system** consists of the following equipment:

- There are 141 stations across Ontario that monitor current conditions and provide site-specific forecasts.
- COMPASS real-time camera images
- Direct Liquid Application (DLA) involves spraying an anti-icing liquid before a storm to prevent

ice and frost from forming and sticking to the pavement. When temperature and other weather conditions permit, anti-icing liquids may be sprayed along a section of highway or at isolated locations that are prone to icing. Some bridge decks have a system that sprays liquid automatically once specific conditions are met.

- Permanent variable message signs provide timely, accurate and useful information to drivers so they can make appropriate choices while travelling. The signs display information related to emergencies, unusual traffic conditions and severe localized highway and weather information.

The **vehicle ITS sub-system** includes the following equipment:

- Global positioning and remote data collection tools are installed in all winter maintenance equipment to provide detailed information to help manage winter maintenance operations. This includes the vehicle's location and speed, as well as other winter maintenance operations underway.
- Electronic spreader controls in trucks allow contractors to set a rate of salt or sand to suit the conditions and keep environmental impacts and material costs down. The control system automatically adjusts the amount of material as the truck speeds up or slows down, which ensures a consistent and efficient application of material on the highway.

Functional architecture

The information provided by the *Ontario 511* includes:

- Road Closures & Restrictions
    - Incidents and Closures
    - Today's Roadwork
    - Planned Roadwork
- Traffic & Road Information
    - Construction
    - Traffic Flow (GTA)
    - High Occupancy Vehicle Lanes (HOV)
- Road Conditions and visibility
- Traffic Cameras
- Other Traveller Information

The description of Road Conditions and Visibility is provided with a three point scale:

- Road is bare, partly covered or covered
- Visibility is Good, fair or poor

<u>Weather and road conditions information collection:</u>
RWIS provide detailed roadside weather conditions and road surface temperature data. A complete RWIS combines the roadside readings with standard meteorological data to provide precision road weather forecasts and pavement condition predictions. Environmental sensor stations (ESS) operate on highways as part of the Road Weather Information System. The highway cameras on these stations are available online for the information of the travelling public.

<u>Information fusion and processing:</u>

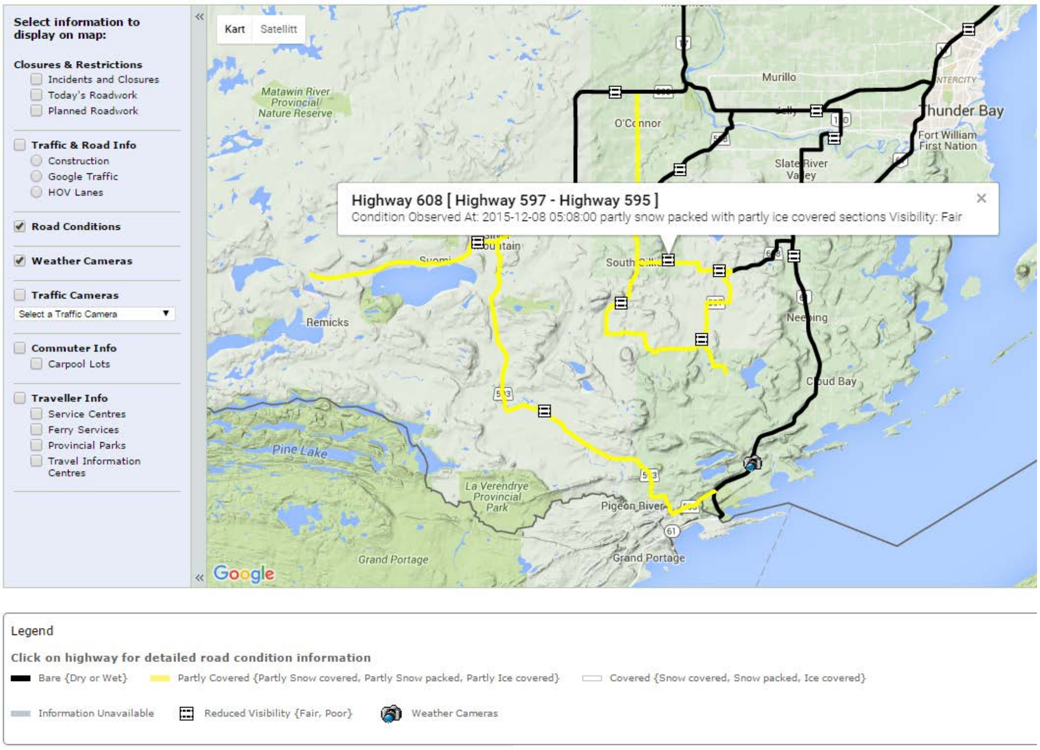
The typical ESS installation includes a short tower, mounting an array of meteorological sensors coupled with a selection of road surface sensors. Processors collect and analyse sensor data transmitting the information to a Central Processing Unit (CPU) or server. The CPU compiles data from all remote sites to provide road managers with a picture of actual weather and road conditions on an entire highway network. Forecasting services then combine collected site information with Environment Canada weather data to predict road temperature and conditions for up to 12 hours.

<u>Weather and road conditions distribution to transport users and maintenance contractors:</u>

Advanced road-weather information system predicts winter weather and highway conditions. This helps maintenance crews prepare the right equipment and materials before a storm, act quickly once the storm arrives and adjust their activities as conditions change. Road conditions and closures are reported to regional communication centres by Area Maintenance Contractors who patrol the highways and the Ontario Provincial Police (OPP).

The Ontario 511 phone line provides up-to-date road condition information for all provincial highways. The information is updated a minimum of five times daily from October to April; or as conditions change.

Error! Reference source not found. shows an example of the interactive map presenting information about the road conditions in the province of Ontario.



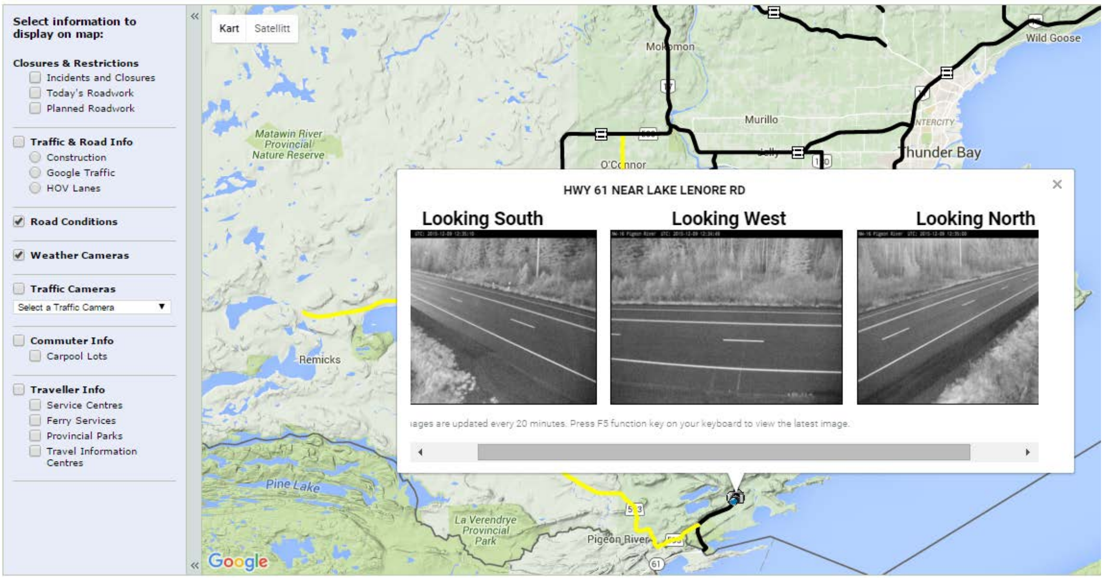


Figure 43 Examples of road conditions in the province of Ontario.

Roles, responsibilities and actors

The roles called ***Road Network operator*** and ***Traffic manager*** are fulfilled by the ministry of Transportation (MTO), affiliated with a number of agencies (independent bodies established by the government but not part of the ministry).

The Winter Road Service commitments are:

- Snow and Ice Control

  To deliver snow and ice control services on provincial highways and get back to bare pavement within standard times for at least 90% after a winter storm.

  There are snow and ice control time standards for highways to be restored to normal conditions after a storm has ended. The standard varies depending on winter traffic volume and road type. For example, the standard is eight hours, after the end of a storm, for high volume highways. Some highways with lower volumes are maintained in snow-packed conditions throughout the winter.

  Ontario's snow and ice control standards are consistent with the best practices used across North America.

- Winter Road Conditions

  To provide winter road condition information for provincially maintained highways to the public in English and French. Information can be accessed by telephone, Internet, or teletypewriter (TTY).

The role, ***Contractor,*** is fulfilled by the 5 maintenance contractors, who are under contract with the ministry. The ministry has 20 area maintenance contracts in place to provide highway maintenance services. Five different contractors perform this work.

The ***Transport users'*** role represent all the users of the Traveller Information Services and the maintenance contractors. The role ***Service provider*** is fulfilled by Environment Canada that provides additional weather information.
Objectives and evaluations
The ministry’s key priorities (June 2015) related to winter highway maintenance include: • keeping Ontario’s highways as safe as possible during winter weather conditions, and • working with contractors, the Ontario Provincial Police and road safety groups to promote safe winter driving and deliver winter highway maintenance services. The Ministry of Transportation monitors winter operations in real time to make sure that all contract requirements are being met.
Any other relevant information
For the 2015/16 winter, the ministry had planned to work with contractors to improve winter maintenance by increasing the use of anti-icing liquids and by making salting and plowing operations more efficient on Ontario's highways (Winter Highway Maintenance action plan, June 2015). They will launch a "track my plow" program in two contract areas with a link from Ontario 511.

H United States

Name of the application
The U.S. Department of Transportation, Federal Highway Administration provides national traffic and road closure information. We describe below the application ClearPath Weather®, a component of the Iteris ClearPath family of traffic and weather solutions, that is a winter road information service that provides decision makers with an easy-to-use display for effectively managing winter weather road issues before, during, and after weather events.
Information sources:
The following references have been used: http://www.fhwa.dot.gov/trafficinfo/index.htm http://www.safetravelusa.com/
Physical architecture

Figure 44 shows the physical infrastructure of the American Weather Information System.

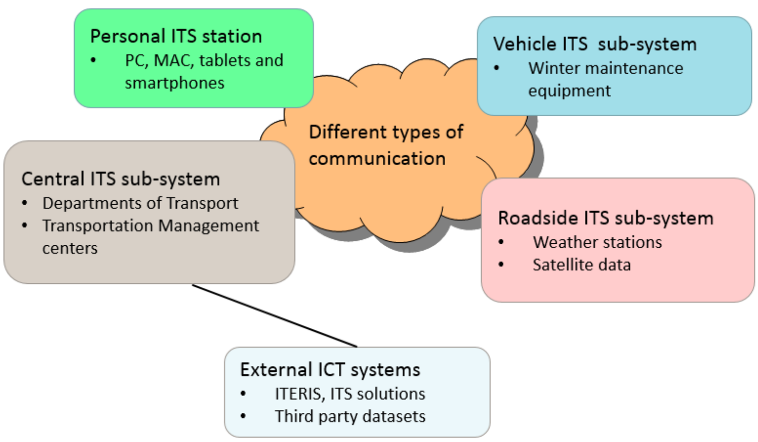


Figure 44 The RWIS in U.S.

The **Personal ITS station** is the transport user PC/MAC or tablet with web browsers. In addition to site-specific forecasts, Iteris' ClearPath Weather empowers users with customizable email or text message alerts for Observed and forecasted weather and pavement conditions and National Weather Service (NWS) watches, warnings, and advisories.

The **Central ITS sub-system** is under the responsibility of the company ITERIS providing information solutions to the transportation market. The Weather Monitoring System of ITERIS utilize highway and atmospheric data to prescribe road maintenance recommendations to the Departments of Transportation of each state. The Iteris' Maintenance Decision Support System web-based solution provides customized solutions to the different Departments of Transport.

The **Roadside ITS sub-system** consists of the following equipment:

- Real-Time Camera image
- Weather stations (precipitation, hail, frost, wind speed, wind direction, temperature, lightning,

SINTEF

etc.)

- In addition, Radar data and satellite imagery as a static image or at 2,6,12 and 24-hour loop intervals

The **vehicle ITS sub-system** includes the following equipment:

- Road maintenance vehicles

Functional architecture

Weather and road conditions information collection:

Each ClearPath Weather forecast provides hourly current and forecasted site-specific road and weather conditions for:

- Pavement/Bridge temperature
- Pavement/Bridge condition
- Pavement/Bridge frost risk (%)
- Route-specific treatment recommendations
- Wind speed and direction
- Visibility and obstructions
- Precipitation type, rate, and accumulations
- Snow accumulations

Information fusion and processing:

ClearPath Weather® API aggregates location-specific weather data, and applies advanced data assimilation and modelling technologies to deliver customizable data solutions. This includes high-resolution APIs and applications ranging from tools for assessing historical weather conditions to both short-term and long-range weather forecasts, all of which can be used independently or integrated into third-party precision applications.

The ClearPath Weather API Capabilities include:

- Ensemble modelling of weather conditions, leveraging a host of computer models
- Real-time performance monitoring to continuously modify forecasts as new information becomes available
- Multi-sensor analyses of current and past weather conditions, utilizing weather stations, radar, satellite, and other remote sensing and weather modelling services
- State-of-the-art International Weather Forecasting Center and Central Processing Center in Grand Forks North Dakota
- Experienced, degreed meteorologists equipped with tools to tailor the firm's digital forecast databases ensure delivery of high fidelity weather information 24/7/365

Each forecast is created with a 48-hour outlook, with regularly scheduled updates every hour. Weather conditions can change rapidly, and Iteris' professional road weather meteorologists are ready to update the forecast to keep decision makers informed with the latest weather information.

Weather and road conditions distribution to transport users and Departments of Transport:

The ClearPath Weather API Features:

- Largest variety of high-quality weather data to include: precipitation, hail, frost, wind speed, wind direction, temperature, lightning, and more

- Capabilities down to 1k x 1k grid resolution
- Surface weather in addition to atmospheric weather
- Configurable, location-based weather alerting service
- Broad suite of high-resolution maps
- Hourly and daily historical weather data
- “Nowcast” of near precipitation amounts and hail risk
- User friendly API delivery infrastructure for integration into third-party applications or services

Maintenance managers are able to view real-time information they need such as looping radar, satellite imagery, and site-specific weather and pavement conditions. Each forecast contains the ideal maintenance action given the current and forecasted weather conditions, an intuitive graphical interface for displaying your information, and a specialized pavement forecast generated by Iteris’ Highway Condition Analysis and Prediction System (HiCAPS™) pavement weather forecasting model.

Figure 45 shows an example of the interactive map presenting information about the road conditions in Montana.

NB: The layout, and the quantity and quality of information provided for each state vary greatly

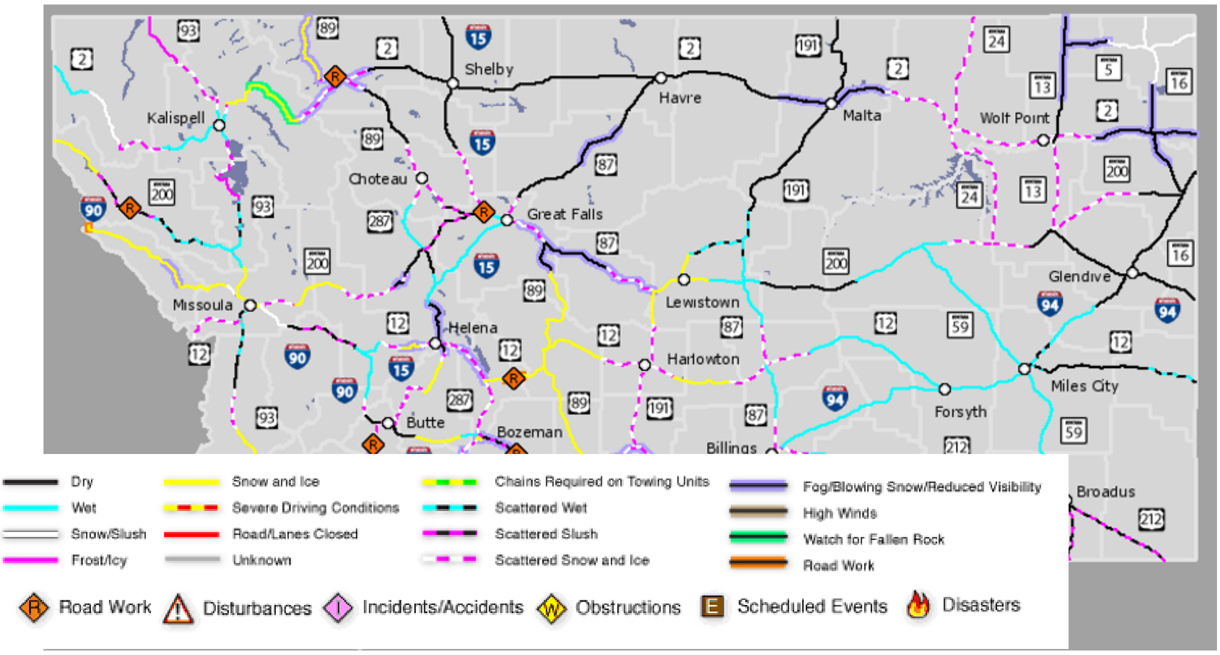


Figure 45 Examples of road conditions in Montana.

Roles, responsibilities and actors

The roles called ***Road Network operator*** and ***Traffic manager*** are fulfilled by the different Departments of Transport. They are responsible for building, maintaining and operating the state's roads, bridges and tunnels.

The role ***Service provider*** is fulfilled by Iteris that provides traffic and weather analytics, and weather APIs.

The role, ***Contractor,*** is fulfilled by the maintenance contractors,

The ***Transport users'*** role represent all the users of the Traveller Information Services and the maintenance contractors.
Objectives and evaluations
The mission of Iteris is to be the leading intelligent traffic management information company, applying advanced technologies to plan, design, integrate, and enable complete solutions that address significant needs in the traffic management market. Benefits of the ClearPath Weather API: • Interactive web-based display • Provides quick and effective access to your preferred data • Pinpoint start/end times for precipitation • One-click menus • Map-based, graph, or table views • Looping radar to show a storm's progress and track • 24/7 weather monitoring by road weather meteorologists • HiCAPS™ pavement forecasts • Custom mobile alerts Return on Investment: • Optimize winter management operations • Improve snow even readiness for staff, equipment, and material • Reduce staffing, fuel, and chemical costs • Pinpoint treatment application • Improve road and public safety • Maintain the flow of commerce
Any other relevant information

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