MOBI-ROMA

State of the Art of Floating Car Measurements

Deliverable Nr 1

December 2011

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This project was initiated by ERA-NET ROAD.

Project Nr. 832702

Project acronym: MOBI-ROMA

Project title:

Mobile Observation Methods for Road Maintenance Assessments

Deliverable Nr 1 – State of the Art of Floating Car Measurements

Due date of deliverable: 31.12.2011

Actual submission date: 30.12.2011

Start date of project: 01.09.2011 End date of project: 31.01.2013

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Version: 1.0

Executive summary

MOBI-ROMA stands for Mobile Observation Methods for Road Maintenance Assessments. The key objectives are to develop, test and evaluate improved, affordable and moderate-cost road condition and performance assessment techniques, which offer new effective tools for monitoring and assessing maintenance needs across Europe.

Since the advent of satellite navigation systems that allow vehicle tracking, there has been considerable research and development of monitoring systems that use intelligent cars as sensors. Having several such cars in a fleet results in FCD systems (Fleet Car Data). Most previous studies have concentrated on the use of FCD for the analysis of the traffic state and to develop better traffic information and telematics services.

In MOBI-ROMA, the emphasis of the study is on road surface condition monitoring using data coming from vehicle's internal sensors through the CAN-bus, or simple devices mounted on the vehicle. Similar techniques with suitable sensors can be used also for assessing strength of road bed or need for winter maintenance. The key target user sector of MOBI-ROMA is road maintenance.

This is the first of four MOBI-ROMA deliverables and describes the background technology and existing operational monitoring methods. Results from some relevant recent projects are presented.

The coming MOBI-ROMA field tests using the developed method are planned to take place mainly in Sweden and Germany, and thus also the current operational routines and methods used in these countries will be discussed in more detail. However, the method developed in MOBI-ROMA is based on global technology that can be implemented and exploited in any European country.

The potential of FCD methods to complement the conventional routines is discussed. A fixed station network has good temporal detection capability (typically few minutes), but due to its high investment cost, the spatial resolution is poor (typically 50-100 kilometers at best). Profilometers and other heavy equipment have high quality and good spatial detection capability, but again due to economic constraints, road stretches can be monitored once per year at best. Thus changes shorter than this period are missed.

FCD methods developed in MOBI-ROMA complement the two conventional data sources by offering moderate-cost way to monitor roads with high spatial as well as temporal resolution. As investment costs are low per unit, the system can be built having several units measuring the roads regularly. To develop such systems, present accessibility problems to CAN-bus data must be first solved. This may require a concerted European-wide action, such as the recent implementation of the eCall system.

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1 Introduction

“ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” was a Coordination Action funded by the 6th Framework Programme of the EC. The partners in ERA-NET ROAD (ENR) were United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.road-era.net). Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research project are Belgium, Denmark, Germany, France, Finland, Netherlands, Norway, Slovenia, Sweden and United Kingdom.

MOBI-ROMA stands for Mobile Observation Methods for Road Maintenance Assessments. The project’s key objectives are to develop, test and evaluate improved affordable and moderate-cost road condition and performance assessment techniques, which offer new effective tools for monitoring and assessing maintenance needs across Europe.

In order to have information about road condition and traffic data for road stretches it is necessary to have access to comprehensive and reliable data that are frequently updated. However, financial constraints mean that this requirement cannot be satisfied for much of the road network. For this reason, road traffic engineers are making increasing use of intelligent vehicles as mobile sensors, so-called “floating cars”, to determine the actual condition that is prevailing. In modern vehicles, the data available include a wide variety of variables that can be acquired in digital form from the vehicle’s data buses.

In MOBI-ROMA, the emphasis of the study is on road surface condition monitoring using data coming from the vehicle’s internal sensors or simple devices mounted on the vehicle. Similar techniques with suitable sensors can be used also for assessing the strength of the road bed or need for winter maintenance.

This report is the first of the four Deliverables of the MOBI-ROMA project. It presents the historical background and state of the art of mobile road condition measurements using satellite positioning techniques and floating car data. First, the key terms FCD and CAN-bus followed by presentation of various satellite navigation systems are defined in Chapter 2. In Chapter 3 current operational road condition observing methods and devices are briefly introduced.

Several base research projects and developing work using these types of data have been carried out around Europe. The aim of the previous work has been in most cases to develop better traffic information and new telematics services which contribute to increasing road safety and driver convenience. A good summary is available e.g. in the report “Road Traffic Data: Collection Methods and Applications” [1]. While research and development on traffic monitoring and ITS applications has been very active in recent years, there is less done for the development of services using such techniques for road management. In Chapter 4 results from some relevant previous projects are presented. MOBI-ROMA team wants to exploit its previous expertise and contribute further to the need of improved and innovative methods, and concentrates on developing affordable, complementary data sources for road management applications. In conclusions the potential of FCD methods to complement the conventional routines is discussed.

The test drives using the developed method are planned to take place mainly in Sweden and Germany, and thus also the current operational routines and methods used in these countries will be discussed in more detail. However, the method developed in MOBI-ROMA is based on global technology that can be implemented and exploited in any European country.

2 Mobile road condition measurement techniques

2.1 Floating car data

In order to understand and analyze how floating car data could be used in traffic management and similar work it is necessary to have a proper definition of the term in question. The following definition of floating car data gives an overview of how the FCD-technology has been used until today.

Floating car data (FCD), also known as floating cellular data, is a method to determine the traffic speed on the road network. It is based on the collection of localization data, speed and direction of travel and time information from mobile phones in vehicles that are being driven. These data are the essential source for traffic information and for most intelligent transportation systems (ITS). This means that every vehicle with an active mobile phone acts as a sensor for the road network. Based on these data, traffic congestions can be identified, travel times can be calculated, and traffic reports can be rapidly generated. In contrast to traffic cameras, number plate recognition systems, and sensor loops embedded in the roadway, no additional hardware on the road network is necessary.

Different types are possible:

Floating cellular data = cellular network **data-based (CDMA, GSM, UMTS, GPRS):** No special devices/hardware is necessary: every switched-on mobile phone becomes a traffic probe and is as such an anonymous source of information. The location of the mobile phone is determined using

(1) triangulation or

(2) the hand-over data stored by the network operator.

As the GSM localization is less accurate than GPS (Global Position Satellite) based systems, lots of devices have to be tracked and complex algorithms need to be used to extract high-quality data. For example, care must be taken not to misinterpret cellular phones on a high speed railway track that runs parallel to the road as incredibly fast journeys along the road. However, the more congestion, the more cars, the more phones and thus more probes. In metropolitan areas, where traffic data are most needed, the distance between antennas is lower and thus the accuracy increases. FCD based on mobile phones believe to have significant advantages over GPS-based or conventional methods such as cameras or street embedded sensors: No infrastructure or hardware is needed to be built in cars or along the road. It is much less expensive, offers more coverage of more streets, it is faster to set up (no work zones) and needs less maintenance. In 2007, GDOT (Government Department of Transportation) accomplished a breakthrough milestone by demonstrating in Atlanta that such system can emulate very well road sensors data for section speeds.

Electronic toll collection device data: ETC transponders, which are uniquely identifiable, may be read not only at toll collection points (e.g. toll bridges) but also at many non-toll locations. This is used as a method to collect traffic flow data (which is anonymized) for the San Francisco Bay Area's 5-1-1 service.

Global Positioning System-based: A small number of cars (typically cars driving in a fleet, such as courier services and taxi drivers) are equipped with a box that contains a GPS receiver. The data are then communicated with the service provider using the regular on-board radio unit or via cellular network data (more expensive).

It is possible that FCD could be used as a surveillance method, although the companies deploying FCD systems give assurances that all data are anonymized in their systems, or kept sufficiently secure to prevent abuses.

2.2 CAN-bus data

Controller–area network (short CAN-bus) is a vehicle-bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a central computer. CAN is a message-based protocol, designed specifically for automotive applications, but the technique is now also used in other areas such as industrial automation and medical equipment.

CAN is one of five protocols used in the vehicle diagnostics standard. This standard has been mandatory for all cars and light trucks sold in the United States since 1996, and a similar standard has been mandatory for all petrol vehicles sold in the European Union since 2001 and all diesel vehicles since 2004.

A modern car may have as many as 70 electronic control units (ECU) for various subsystems. Typically, the biggest processor is the control unit that is related to the engine of the car. Other examples are used for transmission, airbags, antilock braking (ABS), etc.

As modern cars constantly record all these variables it opens up for new improvement and uses of this type of data. The following section describes some projects where the two techniques are used together, FCD-data and CAN-bus data, in order to evaluate how good this type of information can be for example from a road maintenance point of view.

Information that can be achieved via the CAN-bus are signals from all the electrical equipment in a modern car, such as wipers, radio and air condition. It is also possible to get information about lateral and longitudinal acceleration, speed, engine speed, steering angle, throttle position, etc. which can be used to analyze the road and its condition. By using an external computer, with usable software, the CAN-bus signals can be logged and analyzed.

By analyzing the data with different algorithms and methods, it is possible to get comprehensive information about the state of a road. When comparing signals from the anti-lock braking system (ABS) and the electronic stability control (ESC) together with the surrounding temperature, it is possible to evaluate if there is a risk of icy roads or if some types of pavements are more slippery than others. The quality of the pavement can also be evaluated when analyzing signals from the acceleration sensors. The data from the CAN-signals can also be used to analyze driver behavior. This can in turn be used to improve road intervals where accidents are more frequent.

The major problem by using the CAN-signals is that different car models have different configuration on their signals. This implies that it is not possible to just plug in a cable and get the desired information from the car. Specific permits and configuration codes are necessary to be achieved from the car developer before any data logging can be done. Table 1 shows the signals used in the MOBI-ROMA field tests.

Table 1 CAN-signals that are used in the MOBI-ROMA project.

Signals	Description
Accelerometer	Measure of the accelerations in the car. Signals with low frequency show curves, higher frequencies shows vibrations from the road.
Speed	Indicates the speed of the car. Both calculated as the average of the two front wheels and an estimation of the vehicle speed over the ground.
Heading	Registers the angle of the steering wheel to estimate the heading of the car.
GPS-Signals	A CAN-connected GPS to record the time and position of the car.

There are CAN-signals that are regulated to be mandatory in all vehicle brands and models, depending on the engine fuel. The purpose of these regulated signals is to establish emission standards and requirements for onboard diagnostic (OBD) systems, a short selection of these signals are shown in Table 2.

Table 2 Selection of some regulated CAN-signals for gasoline/spark-ignited engines in OBD-II [2].

Signal	Description
Catalyst Monitoring	Control of the catalytic conversion of the exhaust gas.
Heated Catalyst Monitoring	Verifies the heating of all heated catalyst systems.
Misfire Monitoring	Monitor the engine for misfire causing catalyst damage or excess emissions.
Evaporative System Monitoring	Control of the total evaporating system and verification of purge flow from the system.
Fuel System Monitoring	Supervise the fuel system to determine its ability to provide compliance with emission standards.
Exhaust Gas Sensor Monitoring	Monitors the output voltage, response rate and any other parameter on sensors that can affect the emissions.
Engine Cooling System Monitoring	Supervise the thermostat for proper operation.
Cold Start Emission Reduction Strategy Monitoring	Control of all systems used during a cold start to reduce emissions.

2.3 Global Navigation Satellite Systems

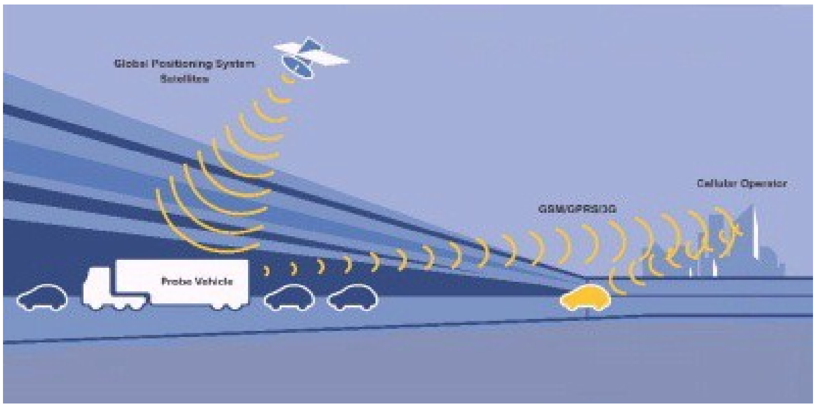


Figure 1 The use of Global Positioning System satellites and data communications in Floating Car applications

The key facilitator for the development of FCD systems has been the advent of global navigation satellite systems (GNSS), allowing continuous tracking of vehicles. The first and most widely used is the Global Positioning Sysem GPS of the United States, which became fully operational in 1994. The system was developed and intended for military use, but since its large benefits were realised by the community, the signal was declared as national assett and secured also for the civil use in 1996. Since then, a multitude of applications emerged, of which car navigators spread to general road users very rapidly. In road management the first applications tracked the positions of snow ploughs and other vehicles, helping the managers in their operations. Output of one such commercial software is shown in Figure 2.

The first FCD field tests were conducted with cars equipped with GPS receivers. Today most smartphones have embedded GPS receivers and thus data communication can be built on cheap on-the-shelf consumer communication systems and devices. One example of such existing system for slipperiness detection is presented in Chapter 4.5.

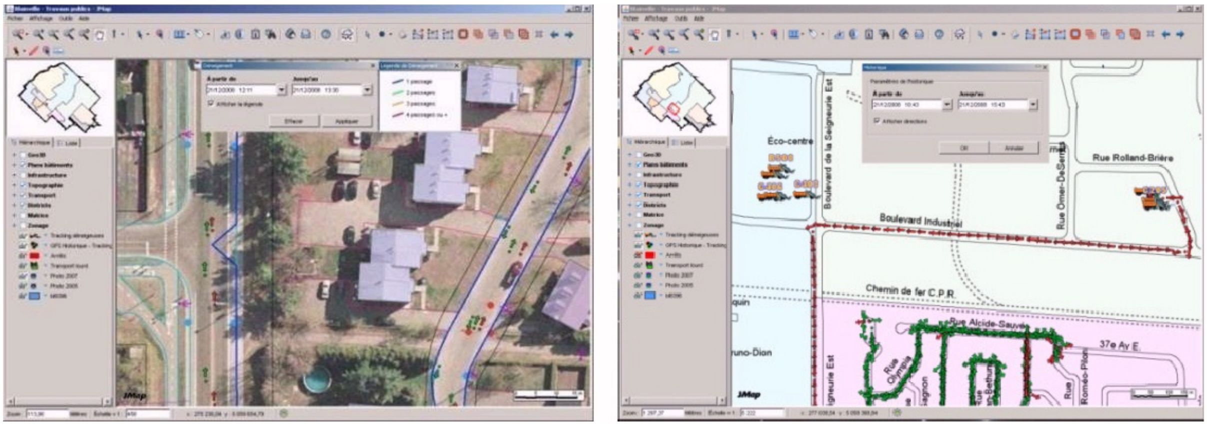


Figure 2 Examples of user interface of tracking service for road operators by K2 Geospatial [3].

Other existing GNSS systems are the Russian GLONASS, which was opened for civilian use in 2007, and is just recently been added as an alternative to consumer smartphones (Nokia). The European Galileo system has been severly delayed from its original implementation plan, but it is now estimated to become operational in 2014 with full completion in 2019. The advantage of Galileo will be a better meter-class tracking accuracy, which would allow tracking of separate lanes in road applications (see Ch. 4.5 for some results). China and India are also developing their own GNSS systems.

3 Current operational systems and practices

Currently road conditions are monitored with several devices and methods. The information coming from fixed road-side stations is combined to data gathered from monitoring vehicles. The devices include e.g. profilometers based on laser techonology, accelerometers, optical remote monitors and several types of friction measuring devices. In the following, some of these used regularly in current operations and in earlier research projects are presented.

3.1 Road condition measuring in Germany

In Germany the Federal Highway Research Institute (BASt) is a technical and scientific institute under the Federal Ministry of Transport, Building and Urban Development (BMVBS). They are responsible for organising and supervising the measurement procedure and campaigns for road monitoring and assessment (sub-section S1 in their organisational structure).

The German network of federal arterial roads includes approximately 12,000 kilometres of federal motorways and 41,000 kilometres of federal roads and constitutes a considerable part of the federal assets. Current and future maintenance of federal arterial roads is therefore a high-priority task to ensure the long-term preservation of mobility for the economy and the society. The design and operation of technically and economically optimised maintenance planning must be based on predictions that facilitate the best allocation of resources. A regular condition registration and evaluation of federal arterial roads is performed for this purpose.

The S1 sub-section has the task of ensuring the quality of the Road Monitoring and Assessment (ZEB). This includes the use of special measuring systems for accepting and controlling the measuring vehicles used in the registration as well as the coordination of the ZEB participants in the federal government and the federal states as well as the ZEB contractors. The S1 sub-section also handles project management for checking, processing and evaluation of the data collected.

The data collected are also used in the Pavement Management System, which facilitates predictions of the development of road conditions. This provides an important base for the future allocation of the available financial means. The sub-section participates in the further development of the Pavement Management System.

Ongoing research is being conducted to improve and automate the measurement of the grip, evenness and substance of the surface to ensure that the registration of the road surface properties remains state of the art.

The acceptance and calibration of measuring systems of building contractors is an additional important task. Appropriate training is provided for the drivers of the SKM vehicles. [4]

The principles of ZEB state that roads must afford safe driving, withstand the exerted loads, provide a certain level of driving comfort, minimize rolling noise and be as durable as possible. Roads are inspected regularly by experts from the highway maintenance departments to permit early detection of damage and deficiencies and ensure compliance with traffic safety standards.

Road maintenance costs money and must be performed with foresight. For this purpose, it is necessary to collect large amounts of data. Visual inspection alone is not sufficient here. Technical measurement and recording techniques today permit objective analyses of surface conditions. The measurement vehicles are operated in regular traffic without disrupting its flow.

The Federal Highway Research Institute participates in developing, optimizing and approving such measurement systems, also on an international level. These systems are used to record road surface condition parameters throughout the network of highways and main roads.

For instance, transverse and longitudinal evenness are measured with vehicles employing laser technology. Traction is measured with a transversely mounted wheel. Surface texture is scanned by video cameras and recorded digitally.

The measured data are used to calculate condition variables. Grades ranging from 1 (very good) to 5 (very poor) are used to characterize an investigated road's condition. The ratings are made up of utility and consistency components in accordance with a defined weighting scheme. The utility component indicates the level of safety and comfort for road users. The consistency component mainly indicates road maintenance results. Both components together form the overall rating.

Individually determined condition parameters and associated values are displayed on special maps. This provides an overview of road network conditions and serves as a basis for planning road maintenance measures.

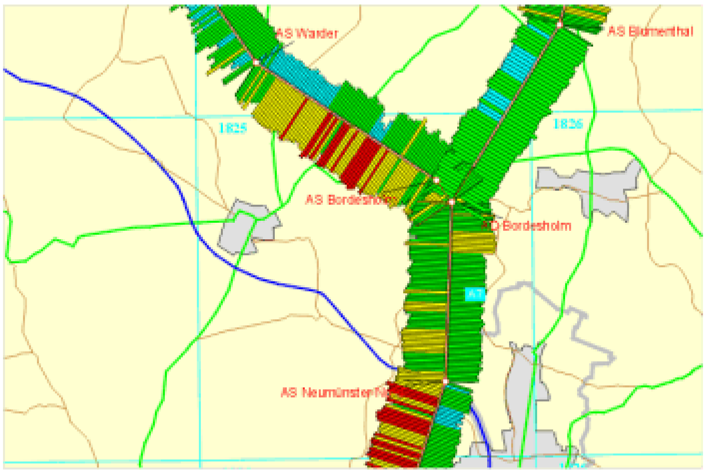


Figure 3 Road surface conditions - network overview

Detailed data and information on all interstate roads are acquired during regular condition checks. The obtained results and findings are channelled to the Federal Highway Information System (BISStra) where they serve, in particular, as a basis for decision-making. [5]

ZEB – Road Monitoring and Assessment – the procedure

The procedure ‚condition monitoring and assessment of road surfaces' has been jointly developed and implemented by the Federal Ministry for Transport, Building and Urban Development (BMVBS) and the German Länder (federal states).

The objective of the standardised procedure for road monitoring and assessment (ZEB), is to provide a picture of the road surface by metrological appraisal through vehicles driving at normal speed, and to evaluate the information. The procedure was first carried out in 1991 and has been repeated regularly since then.

The measurement procedure for the so-called **substance characteristics**, i.e. longitudinal evenness, transversal evenness, traction and consistency attributes, is a continuous process over four years with no particular distinction between summer and winter. It captures the entire network of national and federal roads. The procedure is divided into two measurement campaigns each running over two years – the first dealing with data collection on national highways and the second on federal roads.

The measurement is organised in three phases: phase 1 measures the longitudinal and transversal evenness, phase 2 measures traction and phase 3 captures a picture of the road surface. In a fourth phase the collected data are being assessed and evaluated.

In coordination with the national ministry the German Länder issue an invitation to tender for phases 1-3. Phase 4 is being put out to tender by the National Highway Research Institute who constitute the executive board in the context of the ZEB procedure and who hold responsible for the quality management activities. They also carry out some quality assurance activities.

The ZEB procedure is continuously being updated and developed further through findings from research and technical innovations. It is also being applied to the subordinate network (i.e. from state roads down to communal roads).

In practice, the measurements are carried out by special vehicles which can drive on the road at moderate speed without interrupting the traffic flow. The temporary license for these vehicles is issued by the BASt. There are special regulations to comply with, e.g. each data collection has to be documented by a front mounted video camera and the personnel needs specific training to be eligible to conduct the measurements.

The condition characteristics are related to practical characteristics, such as safety of road users, and to substance characteristics (asset). They are categorised in condition values and standardised. If the warning level has been reached the planning of suitable maintenance measures has to be taken up. Reaching a threshold level automatically leads to structural measures or at least to restrictions for traffic.

From model calculations it can be estimated how the road condition is going to be in relation to the effective allocation of resources.

Altogether, 20-25,000 kilometres of road are being measured. On highways all lanes are being looked at, whereas on federal roads only one lane (i.e. one direction) is being measured. The reason for this being the better cost-benefit-ratio: the gain in information from measuring both directions is smaller related to the additional costs.

The costs for the measurement campaign are approx. 1-3 Mio. EUR per year.

BASt uses data from several special instruments that measure specific properties of the road: Longitudinal evenness, transversal evenness, traction, and consistency of the road surface. Figure 4 shows vehicles designed for these measurements: EFA eveness measuring vehicle for carriageway surface analysis using five laser sensors, which can be used also for measuring and analyzing longitudinal height profiles of roads. SKM Sideway Force Traction Measurement System is using a skewed angle special tyre.

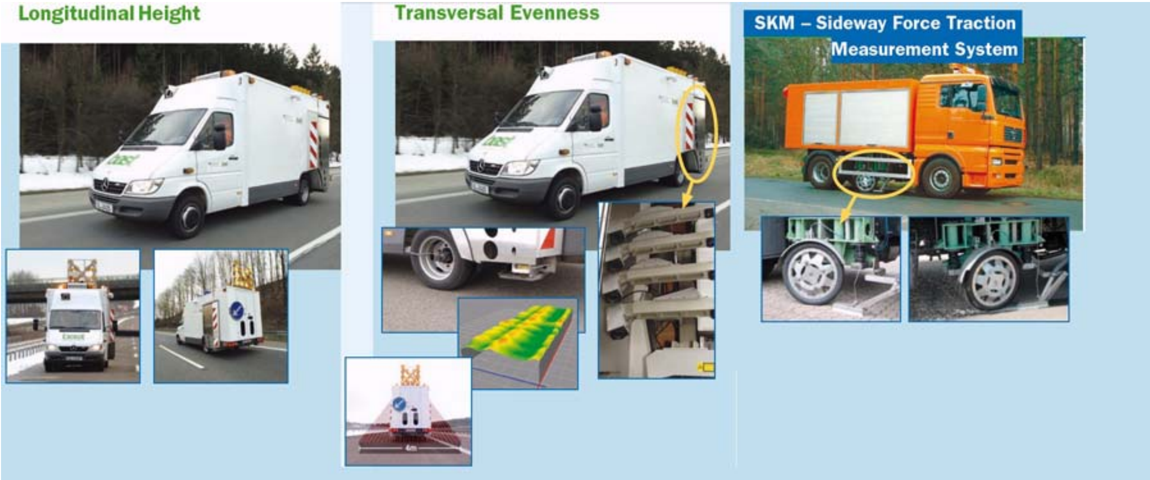


Figure 4 EFA and SKM measuring systems providing data for BASt in Germany.

According to technical personnel of the BASt there is no current research on using floating car measurements for the monitoring and assessment of the road condition.

However, the Technical University of Darmstadt is apparently very active in their research activities dealing with driver assistance systems using sensor data from the car, to be used in modeling the vehicle dynamics.

For road condition monitoring and assessment specific key values are used which so far cannot be obtained from standard cars. For this reason it is difficult to estimate the added value of floating car measurements for this purpose.

There is no cooperation regarding this matter between the BASt and the automotive industry. However, BMW is carrying out research on so-called ‘extended floating car data’ (XFCD), as they have a programme called ConnectedDrive which deals with sensor data on road conditions for driving and the exchange of this information between cars/drivers. So far this research is not connected – apparently due to a lack of interest – to the monitoring and assessment of road conditions in the long term for maintenance reasons.

3.2 *Road laser measurements in Sweden*

In Sweden there are 98400km of state roads and 46500km of municipal roads and streets. The federal roads are comprised of 6400km of E-roads and 8900km of national highways, 11000km of primary country roads and 72100km of remaining country roads. About 19800km of the state road network are gravel roads (ca 20%). [6] The roads paved roads that are the responsibility of Trafikverket are regularly measured by profilograph measuring vehicle (Figure 5). Every year all the E-roads and national highways (Riksvägar) are measured, and what remains of the national road network is measured at least every three years. [7]

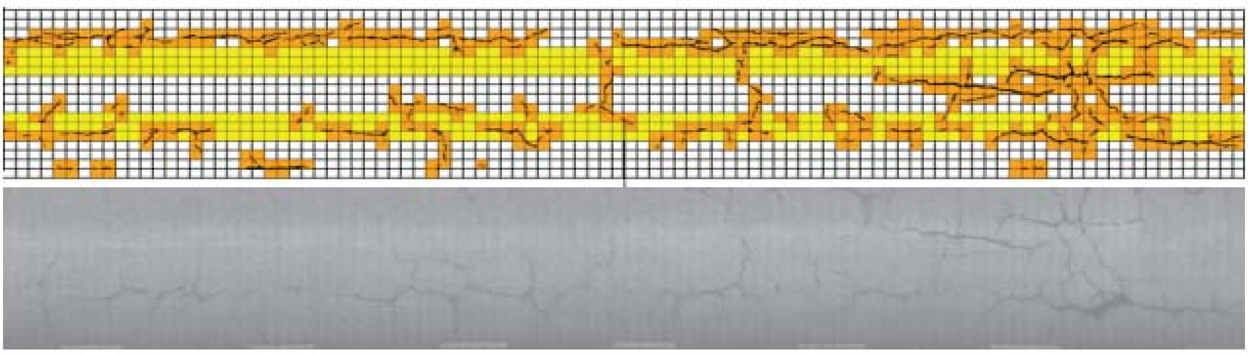
A profilograph is a type of measurement vehicle that is used by for example Vectura, Trafikverket, Luftfartsverket and municipalities. It allows measurements of road surface status in normal traffic speeds.

Figure 5 Profilograph measurement vehicle. [8]

The profilograph has in the front a 2,5 to 3m wide beam, equipped with 17-40 lasers placed ca. 1-3dm apart; closest over the wheel tracks. The beam manages measurements can be wider than the beam thanks to angled lasers at the ends. The profilograph can measure using frequencies from 16 kHz to 64 kHz enabling the profilograph to measure the shape of the road surface and also the fine texture. Inside the measurement beam there are inertia measurement devices that record the beams movement during the ride and thus compensating for the cars movement in the final results. [9] There are also systems in use that instead of fixed lasers utilizes scanning laser system, allowing a higher resolution. [10]

The profilograph measures the pavements road surface texture, cross slope, curvature, longitudinal gradient and rutting. The data collected by a profilograph is used to calculate the International Roughness Index (IRI), which is expressed in units of inches/mile or mm/m. IRI values range from 0 (equivalent to driving on a plate of glass) upwards to several hundred in/mile (a very rough road). [11] The IRI value is used for road management to monitor road safety and quality issues.

Today there is also complementary technologies for crack mapping of the road surface, on such is Rambölls AIES (Automated Image Evaluation System) available. The AIES is an automated system that evaluates detailed photos of the road surface to map cracks, as seen in Fig. 6.



Crack map and road surface image

Figure 6 AIES crack map, source Ramböll. [12]

Consultants active in Sweden are:

- Vectura Consulting AB, prior. Vägverket Konsult
  http://www.vectura.se/sv/Referenser/Sveplasersystem/
- Ramböll RST
  http://rst.ramboll.se/
- Greenwood
  http://www.greenwood.dk/profilograph.php

3.3 Friction monitoring

Due to local climate that can be harsh in wintertime, Northern European countries and those with mountaineous areas have strict rules and quality levels for winter maintenance operations. Control of slipperiness and snow removal is crucial to keep roads safe around the year and requires specific monitoring and services. For friction monitoring there are several types of techniques, but generally accurate assessment of friction on various parts of the road network has been difficult and challenging.

As with pavement condition monitoring, also for friction monitoring there are several methods and sensors, more and less expensive solutions with their pros and cons. There has been a constant need to find better and reasonably priced alternatives, to supplement the costly measurements that are used for reference and calibration. A comprehensive study of methods used globally has been made by Transport Association of Canada in 2009 [13]. Tables 3 and 4 show a summary of some devices and practices used around the world.

There are two basic ways to measure friction: either as spot measurements using short breaking, or continuously based on e.g. skid or tilted wheels, and recently also using optical remote sensors. Several cost-effective new methods have emerged that use either specific accelerometers or even those contained in off-the-shelf smart phones. Figures 7-10 show examples of some systems that are used operationally or are still in test phase.

Quite recently in 2011 the Finnish Transport Agency conducted and published a comparison study of several types of friction monitors, including also these new methods. [14] [15] Comparison tests with six different sensors were made in Sweden in 2008 [16]. The results showed that there is quite large variance in measurements from different sensors and in different conditions. However, also the new cost-effecive methods seem to be reliable enough to support the more expensive methods. One conclusion was a recommended strategy to have few expensive but accurate devices as reference and calibrate the less expensive sensors regularly with these. [14]

The feasible alternative to combine FCD systems and friction measurements would be to use one of the new convenient methods that can be easily mounted on any vehicle. Those using braking tests are not popular in the USA due to the inherent accident risk on roads with heavy traffic. In countries like Finland where traffic is sparse there has been not a single accident observed due to the braking tests and such devices are popularly used. The recently invented light optical sensor RCM411 (Figure 10) [17] providing continous measurement may be a good alternative if braking tests are to be avoided. This device will be tested during the MOBI-ROMA measuring period.

Table 3 Friction devices used or tested by Canadian and international agencies. [13]

Road Agency*	Friction Device
Norway Road Administration	• Norsemeter ROAR • Regular vehicles with ABS and instrumentation to measure deceleration during braking • Digi-slope • OSCAR** • Coralba • Kofriks
Sweden Road Administration	• BV11 • BV14 • Saab Friction Tester • Regular vehicles with ABS and instrumentation to measure deceleration during braking • RT3 • Coralba**
United Kingdom Highways Agency	• SCRIM • GripTester
Finland Road Administration	• Friction measurement truck (TIE 475) • C-trip** • DSC111
Minnesota DOT	• Norsemeter ROAR • English GripTester
Iowa DOT	• Norsemeter ROAR • SALTAR
Michigan DOT	• Norsemeter ROAR
Ohio DOT	• RT3
Virginia DOT	• RT3
Utah DOT	• RT3
Wyoming DOT	• RT3
Ontario MOT	• RT3
Japan	• Bus type full-locked wheel tester • RT3

* Note that these road agencies are the road agencies found in the literature review. This is not an extensive list; other road agencies contacted through the current practices survey have also used or tested friction devices.

Table 4 Current practices of international road agencies. [13]

Road Agency (International)	Use RWIS?	Use Friction as Decision-Making Tool for Winter Maintenance Activities	Conducted Winter Friction Measurements in Research and/or Pilot Tests
Australia Roads and Traffic Authority (New South Wales)	Yes	No	No
Danish Road Directorate	Yes	No	No
Finnish Road Administration	Yes	Yes	Yes
Germany Federal Highway Research Institute (BASt)	Yes	No	Yes
Iowa DOT	Yes	No	Yes
Japan Civil Engineering Research Institute for Cold Region	Yes	No	Yes
Ohio DOT	Yes	Yes	Yes
Norwegian Public Roads Administration	Yes	Yes	Yes
Netherlands Ministry of Transport	Yes	No	No
New Zealand Transport Agency	Yes	No	No
Swedish National Road Administration	Yes	Yes	Yes
United Kingdom Highways Agency	Yes	No	No
Wisconsin DOT	Yes	No	Yes

Figure 7 Montioring vehicle used in the friction monitor comparison study. T_2GO installed on the back wheel, optical DSC111 on the roof and RCM411 at the back. [15]

Figure 8 Instrumentation inside the monitoring vehicle with Eltrip, Gripman and smartphones with accelerometers using µTEC software. [15]

Figure 9 Continuous friction measuring devices RT_3, TWO, ViaFriction and ROAR used in Sweden, Norway and Finland. [14]

Figure 10 Optical remote sensor RWS411 for detection of road conditions. [17]

4 Other mobile road measurement projects

4.1 SRIS

SRIS is an example of a project carried out in Sweden with the aim of doing research within traffic safety using existing in-vehicles technology together with infrastructure in a new and innovative way.

In the SRIS-project data were collected from existing sensors in vehicles about the road condition (ESP, ABS) and other useful information (temperature, windshield wipers etc), and transmitting to a central database. The information was combined with weather information from Road Weather Stations and as result, improved and increased information about the road condition were provided. One of the real benefits with SRIS was that it covers a spatially larger area compared with the fixed positions of the road weather stations and also gives a denser temporal resolution.

SRIS experienced a field-test in the winter 2007/2008 with 100 cars and the result was successful. The result showed that in most cases, the information from the vehicles corresponds with the information from the road weather stations. But there were also situations when SRIS detected slipperiness without warnings from the road weather stations. [18]

Background

Approximately 90% of all new cars in Sweden have ESP (Electronic Stability Program). By using only existing sensors in vehicles, a greater coverage can be established. All vehicles in the SRIS field-test had a special equipment to transmit the signals from the vehicles to a central database. More important is that many new cars have integrated telecommunication equipment, so the real big task in the future is to integrate SRIS in the electrical architecture of the vehicle so the vehicles can send information without the extra equipment that has been used now.

The SRIS test in Sweden was performed by use of 100 cars, 90 of them were located in the Gothenburg area and 10 cars in Stockholm. The car models used in the test were Volvo V70s and Saab 9-5s. The used cars were both company cars and taxis to get a high frequency of usage and driving distance of the cars.

The weather information is collected by 80 Road Weather Stations and transmitted to a central database, located in Borlänge, Sweden. At the same time, vehicles are reporting background data or events of slipperiness from the existing in-vehicle sensors to the same database.

The actual road weather has been collected from road weather stations during the season 2007-2008 and has been sorted by an expert system to classify the different types of slipperiness. The signals from the vehicles have been sorted due to the type of slipperiness that was registered in relation to the closest road weather stations.

Table 5 Indicated probability of slipperiness due to increase in car signals from situations with bad road conditions compared to signals generated during situations with dry asphalt. [18]

	NOT SLIPPERY	RAIN	RAIN ON COLD ROAD	SNOW	FROST
Probability of slipperiness	1	1,03	10	14	3

An important conclusion is that the weather has a major impact on how often the vehicles are reporting events of slipperiness. This means that it is possible to detect and determine the risk and level of slipperiness on the roads. For example if the road condition is snowy there will be a 14-times increase in signals.

The performed field tests show that it is possible to combine the collected data in a useful way to get an increased usability of the provided information. SRIS increases the possibilities to identify severe road conditions. The field test with 100 cars has shown a good result and that it is possible to apply SRIS to more vehicles and gain a growing profit for the society, both for drivers and road maintenance.

The result from the SRIS field-test showed a good result is the test area. An external socio-economic study was also made by Movea where the conclusion is that the system gives a very high socio-economic outcome in relation to the cost for SRIS (positive cost-benefit -ratio).

The economic benefits would be for the road administration who pays for the road maintenance and insurance companies who can lower their costs. But most important of all is that SRIS has a potential to improve the traffic safety which can save lives. SRIS also has a potential to give benefits for the environment avoiding unnecessary road salting.

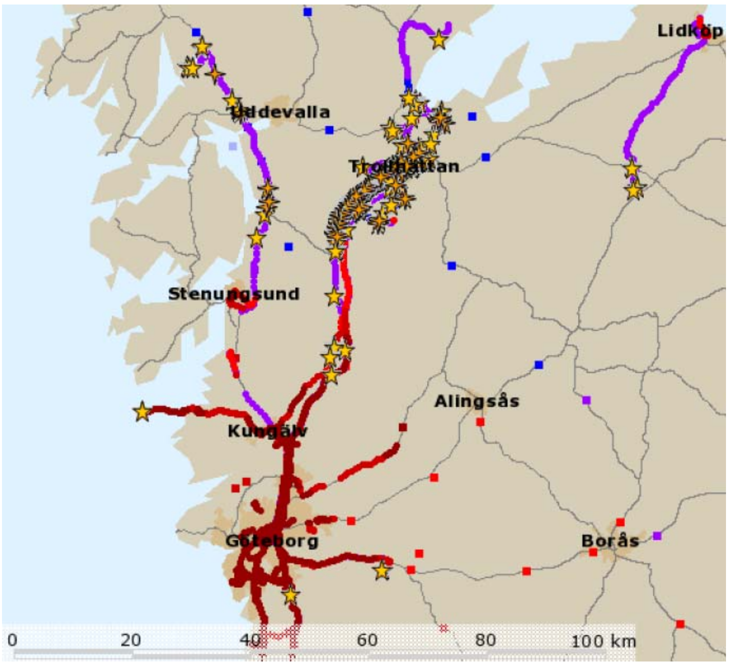


Figure 11 Stars indicate that the anti-brake or anti-spin system in the car fleet have been activated due to severe road conditions. [18]

4.2 *BiFi*

The BiFi project "Bearing information through vehicle intelligence" is an ongoing project in Sweden with the aim of studying if it is possible to map the load/bearing strength of roads by a vehicle-based method. The basic idea is that through combining the vehicle data with weather observations and forecast weather data it is possible to model and forecast the road status according to bearing strength. The results from the project so far are based on field tests in a rough and real environment for determining the load-bearing strength of the roads.

Background

Roads with a high load-bearing capacity are essential for harvesting natural resources and to help keep the countryside open and prosperous. During periods in the spring when the ground frost thaws the load bearing capacity of the forest roads is greatly reduced, leading to road closures. Subsequently, it is not possible to use the roads for transporting heavy goods such as lumber. In order to decrease the costly consequences of road closure the lumber industry needs to build up large stocks and to plan their transport in such a way that secondary stocks can be used. It has been calculated that these measures cost the industry an extra 650 million a year only in Sweden.

And therefore there is a need for a tool for judging the load-bearing capacity of the road network in a detailed and dynamic way that would considerably help to change the current strategy and possibly save the industry significant amounts of money.

Results

The results from the BiFi-project have been very successful. The technology to use vehicles to detect the bearing strength of gravel roads has been found very promising. In part 1 of the BiFi-project an algorithm has been developed based on collected real-time data from a vehicle's standard sensor. Through data analysis, a method of determining the load bearing capacity of the roads that were driven on with cars was established. To test the algorithm and model - extensive field trials have been carried out together with reference measurements. Using the well proven method based on DCP - Dynamic Cone Penetrometer - a comprehensive set of reference data was established. This method was also complemented by measurements using a FWD - falling weight deflectometer. A conclusion from this was that the FWD as a method is not very useful during the thawing period since high water content in the road bed gives rise to errors for the FWD. To ensure the quality from the cars additional sensors were used by reference accelerometers that were fitted to the vehicle in order to give an indication of the quality of the vehicle's own accelerometer data.

Figure 12 Accelerometer used in BiFi project.

Conclusions

- The BiFi-system detects the bearing strength in a way that is in accordance with reference measurements.
- In situ manual observations of the roads are insufficient as a method for decisions about bearing strength.
- There is no such thing as a straight stretch when it comes to gravel roads – this means that a road stretch that looks straight on a map in reality has the potential to give BiFi indications.
- Measurements by the DCP shows that there are a lot of spatial variations that are not possible to detect by manual inspections.
- For future reference measurements the DCP is recommended in favor of the FWD

4.3 ColdSpots

The project ColdSpots (2005-2007) was the start of more comprehensive mobile road condition observing in Finland. The project was initiated after a very serious road accident that was caused by slipperiness due to very small scale super-cooled rain shower. The project was co-funded by the Ministry of Transport and Communications in Finland, Finnish Road Administration, and the consortium of three public and private partners: Foreca Ltd, Destia (formerly Finnish Road Enterprise) and Finnish Meteorological Institute.

Detailed mobile observations of road surface state started in 2006 and results were used in verifications and model development. This was the first time when optical remote sensors (Vaisala DSC111 and DST111) designed for fixed road stations were mounted on a car (Fig. 13). [19] [20] Instruments measure the amount of snow, ice and water on the road surface, air and road surface temperature and air moisture, and friction derived from the measured values. Observations were received every 5 seconds corresponding to some 100 m resolution along the road. The observing car was equipped with a GPS receiver measuring the car position every second, and a laptop that collected measuring data using a Bluetooth connection to the instruments.

The very first field tests immediately revealed the great potential of mobile observations. Observing instruments reacted rapidly to visible changes on the road surface conditions. The found variability between fixed stations was in some cases surprisingly large. One example of results is shown in Fig 14.

Figure 13 The first installation in 2006 using optical remote sensors Vaisala DSC111 and DST111 behind the observing vehicle. [21]

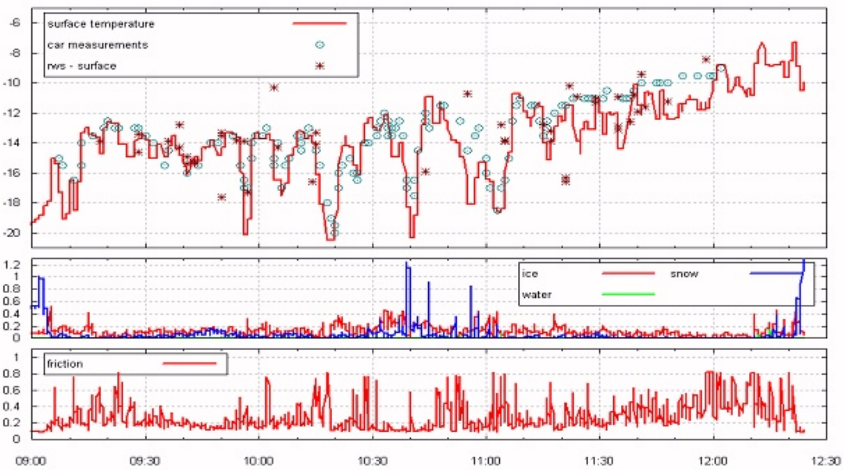


Figure 14 Variability of road conditions on a very cold day. Legend: Upper panel: surface temperature from DST111 (red curve), car (circles) and RW stations (asterisks). Middle panel: Ice, snow and water on the road from DSC111. Lower panel: Friction as calculated from DSC111 output. [21]

4.4 ROADIDEA

ROADIDEA (2007-2010) was a cooperative R&D project co-funded by the European Commission under the 7th Community Framework Programme for Research and Technological Development. Its objective was to study the potential of the European transport service sector for innovations, analysing available data sources, revealing existing problems and bottlenecks, and developing better methods and models to be utilized in service platforms. These are capable of providing new, innovative transport services for various transport user groups. The project had fourteen partners from eight European countries, i.e. Finland, Sweden, the Netherlands, Germany, Italy, Slovenia, Croatia and Hungary. More information and public reports are available from the projects web pages. [22]

Figure 15 Second installation on top of the car in ROADIDEA project (2007-2010). [22]

Mobile observation methods developed in *ColdSpots* were continued during ROADIDEA to gain more information of the variability of road conditions and the local effects of maintenance operations to slipperiness.Sensors were mounted on top to the car to keep lenses more clear during the test drives (Figure 15). In Figure 16, two cases from ROADIDEA measurements are shown. Only values of friction are shown in this case. The first case a) on the upper panel was an extremely slippery evening in a snowfall, and during the first drive friction was varying between 0.1-0.2 because no salting had been done yet (the red curve). One person was killed in an accident due to slipperiness near the measuring area. The second drive through the same road was done after the salting had been just performed, and the effect is clearly visible (green curve). A third drive half an hour later gives even somewhat better (higher) friction, as the salt has had time to melt the ice on the road.

The second drive on the lower panel b) started through an area filled with super-cooled fog. Friction was at places very low but there was large local variability inside the fog area. After coming out of the cloud, the friction was at a maximum corresponding to a dry road. The photograph in the back of Fig. 16 shows how the instruments had been completely covered with frost after the fog drive.

Figure 16 Effects of a) salting and b) super-cooled fog on local variability of friction. [23]

The collected data was used to develop a new friction model and slipperiness warning service with a pilot name "Pulp Friction". The initial service idea went through the complete development cycle and reached a level of first pilot version of the service with user tests. Demonstration is shown in Fig. 17 and on the ROADIDEA web site.

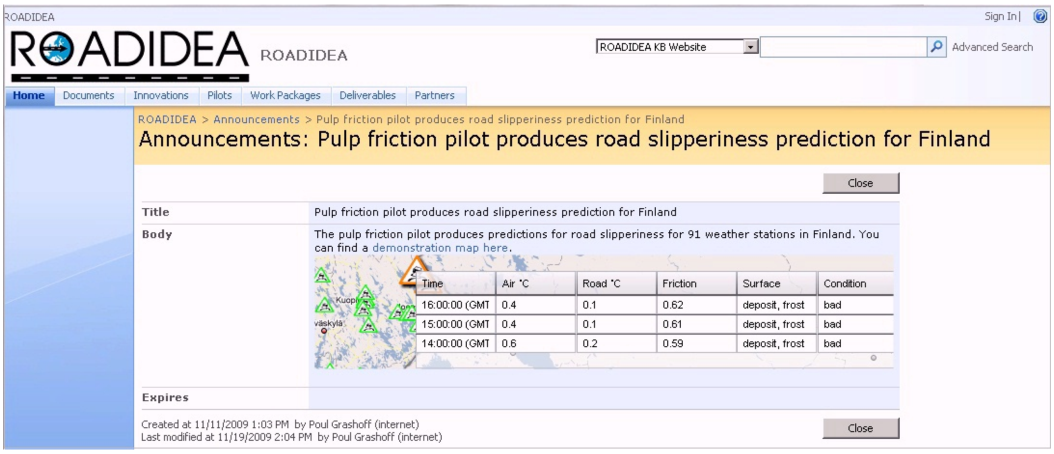


Figure 17 ROADIDEA pilot service "Pulp Friction". [22]

4.5 GalileoCast

One specific topic has been to develop hybrid (i.e. fixed and mobile combined) observing systems to study local variability of road surface conditions. The question is what would be the optimum combination of fixed and mobile observing units to gain maximum detectability with highest cost-efficiency. The field tests performed during winter months in Southern Finland provided a sample of mobile observations, which was compared to the output from the fixed network of operational Road Weather Information System. Finland is covered with a network of some 500 road weather stations making automatic measurements every 30 minutes.

In the European project GalileoCast [24], the combination of the optimal set of fixed and mobile measurements was studied. The most important feature of different kinds of observation systems is their detection capability (DC) of meteorological phenomena that can cause slipperiness or other risks to drivers. Generally, these phenomena can be classified according to their size in synoptic scale (100 km), meso-scale (10 km) and micro scale (1 km) features. Each of these have a typical life time (24 h, 6 h and 1 h, respectively) causing a swath of reduced friction while passing over the area. In addition, local topographic effects cause spots that are prone to slipperiness. In the following Table 3 the detection capability of fixed, mobile and hybrid (fixed and mobile combined) observing networks are compared. The fixed network corresponds to that presently in place in Finland, which has an area of 300.000 km^2. The hypothetical mobile system consists of 10 units that measure 250 km of road 4 times per day. Spatial resolution is superb, but the system has poor temporal resolution compared to the fixed system. A hybrid system contains both good features and gives the best detection capability [x].

Table 6. Estimates of the detection capability (DC) of present fixed road weather station network in Finland, a hypothetical mobile system of 10 units and a hybrid system combining both data sources. [24]

Observing system	Fixed	Mobile	Hybrid
Measurement units	Equipped masts	Equipped cars with GNSS	Both masts and cars
Total units	80	10	90
Spatial resolution	60 km	100 m	60 km & 100 m
Temporal resolution	30 min	3 sec	30 min & 3 sec
Observations / day	3840	172800	176640
DC synoptic 100 km	100 %	100 %	100%
DC meso-scale 10 km	40 %	15 %	55 %
DC micro-scale 1 km	1 %	5 %	6 %
DC topographic effects	No	Yes	Yes
DC lanes, GPS	No	No	No
DC lanes, Galileo	No	Yes	Yes

4.5 INTRO

INTRO (Intelligent Roads) was active in 2005-2008 and co-financed by the EC in the 6th Framework Programme, with a total budget of 3,5 M€ [25]. Objective was to study several technologies to add “intelligence” to roads for increased safety, better road operations and maintenance. Fig. 18 shows the general, layered structure of Intelligent roads architecture, with those areas in INTRO highlighted in green.

Floating car data was chosen as alternative data source and tested for better monitoring of friction and pavement condition. Tests using CAN bus output were performed in urban as well as rural areas and on bridges, using two probe vehicles in Sweden and two in the UK. The outcome of INTRO field tests was that the concept was not well suited for urban and inner city environments due to misconceptions arising from not real road defects but also from road junctions, parked cars, etc. Trials on rural roads gave better and more consistent results.

INTRO field tests will provide a valuable comparison data set to MOBI-ROMA. INTRO tests with the intelligent vehicles showed that the use of a dedicated fleet equipped with the CAN bus readers and GPS functionality, preferably with added vertical acceleration sensors, is a good set up to obtain up-to-date information of road defects. Probe vehicles are cheaper and easier useable than the specific technologies used for assessing the condition of the road surface. However, the information from the probe vehicles is less accurate.

In future scenario discussion, INTRO concluded that road status monitoring is expected to increase significantly by means of in situ measurements combined with floating car data for disturbed statistic patterns. This would cover both primary and secondary roads, thus enhancing the feasibility of conventional methods that can normally be justified on busy and strategic routes. It was also concluded that monitoring by means of probe vehicles will be a cost-effective measure, enabling more effective target maintenance, leading to road authorities optimizing their resources. FCD can be used further to estimate the performance of the network, e.g. congestion level, amount of emission and travel time. Road operators can use this information to select best management strategy.

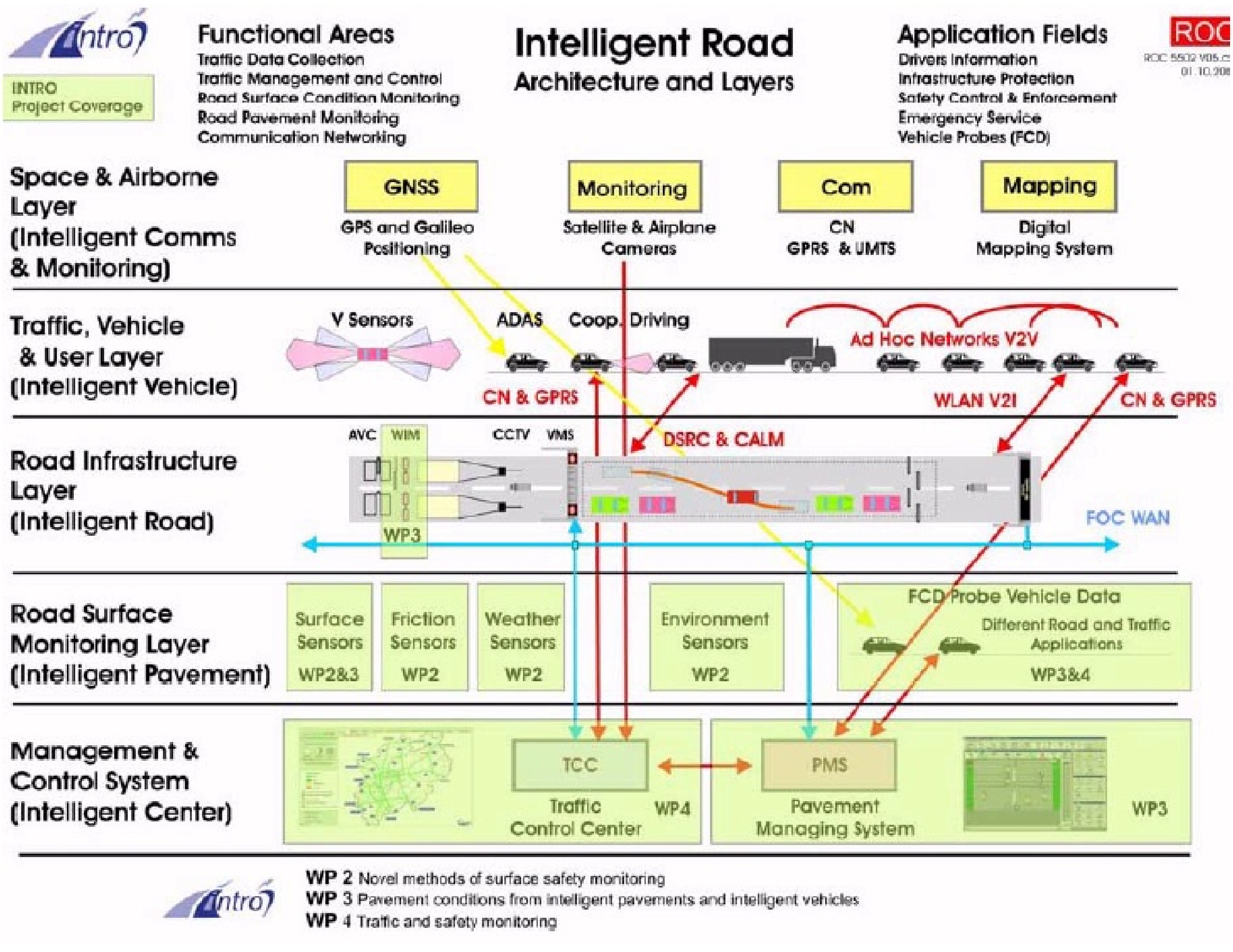


Figure 18 General scheme of INTRO layered architecture, green sections being part of the project. WPs relevant to MOBI-ROMA are on the right of the second layer (WP3&4). [26]

4.6 Research projects in Germany

Research projects run by the National Highway Research Institute relevant to road monitoring and assessment are among others:

Updating of road monitoring and assessment (ZEB) - ongoing –

The aim of this project is to improve the road monitoring and assessment by analysing the result of recent research projects as well as from applying the ZEB at Länder level and prepare a proposal for decision making.

Development of automated feature recognition as part of phase 3 – finished –

For the recognition and assessment of road damage, currently, images of the carriageway surface are recorded and evaluated by means of a damage catalogue. The images have previously been analysed manually, which can result in different assessments.

To guarantee consistent evaluation, software for semi-automatic feature search and analysis of surface defects is to be developed within the framework of the present research project. The feasibility of such a system was already analysed in the previous project.

In order to investigate the practicality of such an assistance system, a workstation is to be installed and equipped with software which is to be developed accordingly. Furthermore, it is to be examined to what extent surface damage analysis could be automated. It should be further investigated to what extent the detected characteristic classes can be expanded (i.e. classification of damage characteristics).

Improvements to practical evaluations of road condition – finished –

Diplom-Ingenieur Stefan Ortelt, Dießen
Forschung Straßenbau und Straßenverkehrstechnik, Heft 950, 2007

5 Conclusions

This state-of-the-art analysis presented the principles of satellite tracking, CAN-bus data retrieval and Floating Car Data systems, assuming that this could be a new cost-effective source of monitoring data for road management assessments. Current practices and techniques were presented as well.

Table 7 summarises the analysis of how the different monitoring techniques reveal different temporal and spatial phenomena affecting the road network. A fixed station network has good temporal detection capability (typically few minutes), but due to its high investment cost, the spatial resolution is poor (typically 50-100 kilometers at best). Profilometers and other heavy equipment have good spatial detection capability, but again due to economic constraints, road stretches can be monitored with these once per year at best. Thus changes shorter than this period are missed.

FCD methods developed in MOBI-ROMA complement these two sources by offering moderate-cost way to monitor roads with high spatial as well as temporal resolution. As investment costs are low per unit, the system can be built having several units measuring the roads regularly. To develop such systems, present accessibility problems to CAN-bus data must be solved first. This may require a concerted European-wide action such as the implementation of the eCall system.

Table 7 Schematic analysis of spatial and temporal detection capability of different road monitoring methods.

Detection method	Temporal resolution	Spatial resolution	Pros	Cons
Fixed road stations	10-30 min typically	50-100 km at best	Good detection quality if well calibrated. Multiple instruments.	Expensive per unit. Network does not reveal local effects, which may be dangerous to drivers.
Profilometers and other heavy monitoring equipment	Continuous during the monitoring drive, but repeated only ~ annually	Continuous along highways on selected paths	Good detection quality of specific road conditions	Expensive and thus cannot be repeated often.
Light monitoring equipment (e.g. for friction)	Continuous during the monitoring drive, but repeated only ~ weekly.	Continuous along highways on selected paths	Good enough detection quality with reasonable price.	Expensive to use continuously on the road network.
FCD using CAN-bus data	Continuous during the monitoring drive, can be repeated ~ daily	Continuous along highways and lesser road network on selected paths	Can be organized with reasonable costs using ordinary cars, and with good coverage	Accessibility to CAN-bus is presently limited by car manufacturers.

The next phase of MOBI-ROMA is for executing the test drives in Sweden and Germany during the winter and summer seasons, develop measuring algorithms and the pilot user interface for evaluation. The next report due in August 2012 will describe the results of the field tests.

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