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ROADEX III
NORTHERN PERIPHERY

Timo Saarenketo

MONITORING LOW VOLUME ROADS

Executive Summary

Monitoring Low Volume Roads
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PREFACE

The report that follows is an executive summary of the 2005 ROADEX II report "Monitoring, Communication and Information Systems & Tools for Focusing Actions" by Timo Saarenketo of Roadscanners Oy, Finland.

It provides a general description of the main areas for monitoring road condition and summarizes current and future processes, including sensor technology, as well as presenting innovative ideas for new monitoring systems that could be used in low volume road condition management in the Northern Periphery area.

The report was written by Timo Saarenketo from Roadscanners Oy, Finland. Ron Munro, project manager of the ROADEX III Project, checked the language. Mika Pyhähuhta of Laboratorio Uleåborg designed the graphic layout

The authors would like to thank the ROADEX III Steering Committee for its encouragement and guidance in this work.

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Chapter 1. Introduction

1.1 ROADEX -PROJECT

The ROADEX Project is a technical co-operation between roads organisations across northern Europe that aims to share roads related information and research between the partners.

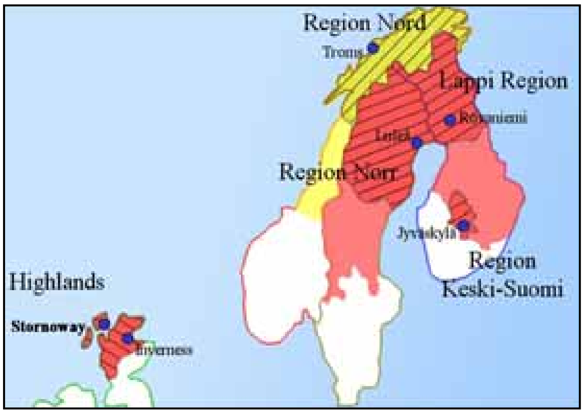

Figure 1: The Northern Periphery Area and Roadex II partners

The Project was started in 1998 as a 3 year pilot co-operation between the roads districts of Finnish Lapland, Troms County of Norway, the Northern Region of Sweden and The Highland Council of Scotland and this was later followed up with a second project, ROADEX II, from 2002 to 2005.

The partners in the ROADEX II Project comprised public road administrations, forestry organizations, forest companies and haulage organizations from regions in the Northern Periphery. These were The Highland Council, Forest Enterprise & The Western Isles Council from Scotland. The Region Nord of The Norwegian Public Roads Administration and The Norwegian Road Haulage Association, The Northern Region of The Swedish Road Administration and The Lappi and Keski-Suomi Regions of The Finnish National Roads Administration. (These latter Finnish Regions also received aid from their local forest industry organisations of Metsähallitus, Lapin Metsäkeskus, Metsäliitto & Stora-Enso.)

The goal of the project was to develop ways for interactive and innovative road condition management of low traffic volume roads integrating the needs of local industry, society and roads organisations. 8 formal reports were published together with a project DVD and full copies of all reports are available for download at the ROADEX web site at www.roadex.org.

This Executive Summary report is one of 8 summaries that have been prepared under the direction of the ROADEX III project (2006-2007), a new Project where the named project Partners above were joined by the additional Northern Periphery Partners of the Municipality of Sisimiut, Greenland, The Iceland Public Roads Administration and the Finnish Road Administration Region of Savo-Karjala.

1.2 NEW TECHNOLOGIES TO IMPROVE THE FOCUS ON LOW VOLUME ROADS

It must now be accepted as a fact of life for the management of low volume roads in the Northern Periphery that there will be little likelihood of major increases in government funding for the foreseeable future to improve their condition. New technologies will therefore be required to play a greater role in maintaining and improving the aging low volume road network across the area and any investments granted will have to be made more productive. The key to answering this challenge is to improve focus. Improved focus means that issues such as 1) road user needs, 2) timing, 3) location and 4) problem diagnosis and correct measures for both maintenance and rehabilitation actions should be examined and considered carefully.

In the last few years, there has been a rapid development of modern sensor technology and when this can be combined with the new positioning techniques (GPS) and wireless communication and information technology, numerous opportunities will be able to be exploited in low volume road condition management. New sensors, installed on vehicles using the rural road network on a daily basis, are generating a range of new possibilities to focus and intensify operations on the road network.

The main work of this subproject has been to prepare a report that examines the possibilities of using new sensor technology to collect real time information on road condition, vehicle loads, traffic safety hazards etc, and then transmit the data for further processing and analysis – and, if necessary, then pass the resulting information on to local maintenance crews and road users.

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Chapter 2. Monitoring

Low volume road condition management in the Northern Periphery area can in general be divided into four critical areas each having special problems that require special monitoring techniques and measures. These four areas are winter maintenance, handling the functional condition of the road in summer, handling the structural condition of the road network and managing spring thaw weakening. Figure 2 further describes these areas and the main concerns related to each one. In addition a fifth condition in the future could be ‘environmental condition’, which has recently been mentioned in the latest EU reports on traffic infrastructure management. Additionally there are also some other specific areas, such as freight management, axle loads and total weights of heavy vehicles and road users needs, that also need to be monitored on low volume roads. These topics will be discussed later in this report.

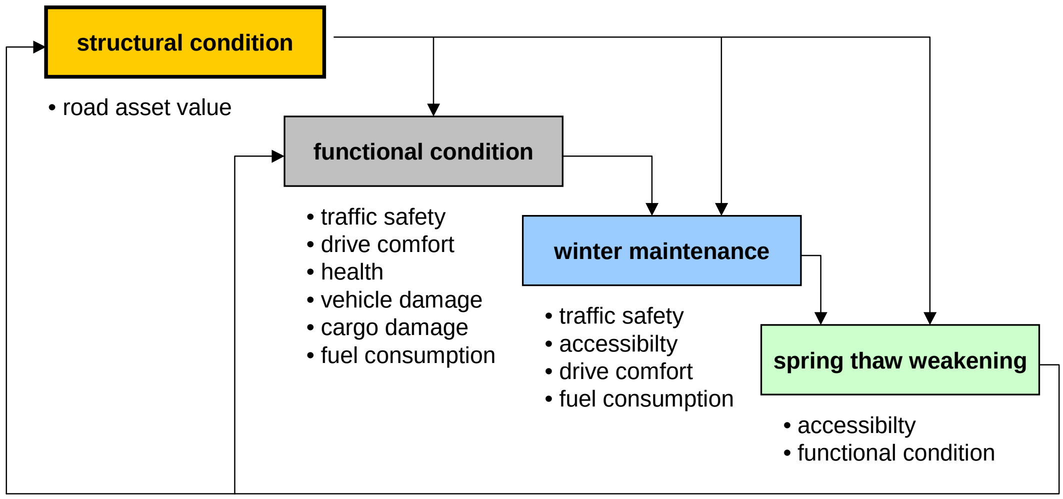

Figure 2. The main road condition management areas in the Northern Periphery, their internal relationships and the main concerns for road owners.

Table 1 gives a summary of the critical parameters in each management field, the current key monitoring tools as well as the consequences for road owners and road users if the measures mentioned are not carried out at the right time and in the right way. Later in this report new monitoring technologies and parameters will be also discussed.

Table 1. Low traffic volume road management categories, their critical parameters, monitoring techniques and consequences for road owners and users if appropriate measures are not scheduled.

	Winter maintenance	Functional condition	Structural condition	Spring thaw weakening
Critical parameters	- Friction (ice, black ice) - Compacted snow - Drifting snow - “Snow smoke”	All roads - longitudinal roughness - friction - bumps - rutting - potholes Gravel roads - wash boarding - dusting - firmness	- drainage - deflections - frost heave - cracking - permanent deformation (rutting) - roughness - settlement	- permanent deformation (fast rutting) - cracking - road surface becomes plastic
Consequences for road users – if not done properly	- reduced traffic safety delay costs - poor accessibility - reduced drive comfort - Increased fuel consumption	- reduced drive comfort - vibrations leading to poorer health - vehicle damage - increased fuel consumption - reduced traffic safety - delay costs	- no direct effect in short term - reduced functional condition in long term	- reduced drive comfort - increased transportation costs - poor or impossible accessibility - vehicle damage - delay costs
Consequences for road owners – if not done properly	- increased maintenance costs - negative feedback from road users	- increased maintenance costs - negative feedback from road users	- increased maintenance costs - increased rehabilitation costs & frequency - reduced asset value	- increased road damage - increased life cycle costs - load restriction violators - negative road user feedback
Monitoring and survey techniques	- weather stations - weather radars - snow depth sensors - weather forecasts - friction measurement - road users feed-back - visual inspections	- visual inspections - profilometers (paved roads) - accelometer sensors (especially gravel roads) - laser scanners - road users feed-back - instrumented utility vehicles (e.g. post vans)	- moisture sensors - drainage control - FWD - GPR - measurement of the rate of rut development - visual inspection	- DCP - Percostations & similar monitoring stations - temperature probes - FWD (also portable) - visual inspections - road user control

Chapter 3. New winter maintenance monitoring tools and practices

In Northern Periphery road regions the road condition, traffic safety and accessibility during the winter is the biggest concern for road authorities and, as such, the largest share of road maintenance funding is spent on winter maintenance.

Winter maintenance issues were left out of the research of the ROADEX II project due to great differences in winter weather conditions across the Northern Periphery area. However some ideas concerning future monitoring techniques that were discussed during the ROADEX II project and that could be used on low volume roads are presented in the following.

On the low volume road network there are always difficulties with reacting in time to changing winter driving conditions. Weather forecasts, weather stations and weather monitoring systems provide mainly reliable information for road maintenance crews. However, changes in weather can sometimes be so localized or unpredictable that crews do not receive information regarding bad road conditions early enough. One solution to this problem might be to equip the vehicles of local residents (taxis, school buses etc) with devices for remote sensing of road conditions and automated reporting of hazardous conditions.

Given current trends in automobile technology it is not unreasonable to think that, in the future, that most, if not all, cars will be equipped with GPS (global positioning systems) as well as ESP (Electronic Stability Program) or other similar systems that deliver lateral slip control. These systems supplemented with steering angle sensors, yaw-rate sensors and lateral acceleration sensors can provide extremely valuable information regarding winter driving conditions.

In the future school buses, taxis and postal vehicles, for instance, could be further outfitted with these systems that send the GPS coordinates, to a monitoring centre via cellular phone, from places where the ESP system is activated (figure 3). These “red dots” could then be used as indicators that road conditions are poor and maintenance measures might be necessary. A system such as this provides information which, especially for the transmitting vehicle, may be too late, however it still presents an opportunity to warn other road users of the poor driving conditions through radio or other information systems that vehicles may be equipped with. Another advantage of such system is that this information will, in the long term, provide useful information about those road sections that always become slippery first and then maintenance operations or even new structural solutions can be focused on these sections.

Other new technologies that could be used in low volume road condition management are modern weather stations and ultrasound snow depth sensors. Weather stations have traditionally been installed only on main roads because of their high price and their need for close proximity to telephone lines. But now the price of weather stations has gone down with the cost for the instruments required for a single station falling in the range of 1000 – 2000 euros. The transmission of data can be handled through the cellular phone network and a power supply can be generated through solar panels. These stations could be installed at the same locations as spring thaw weakening monitoring stations and with the added possibility of integrating them with the station so that rainfall and evaporation could be monitored (figure 4). Installing such sensors would not only help with monitoring snow depth for the purpose of guiding winter maintenance actions but this system could be also used to monitor how effectively contractors handle winter maintenance operations.

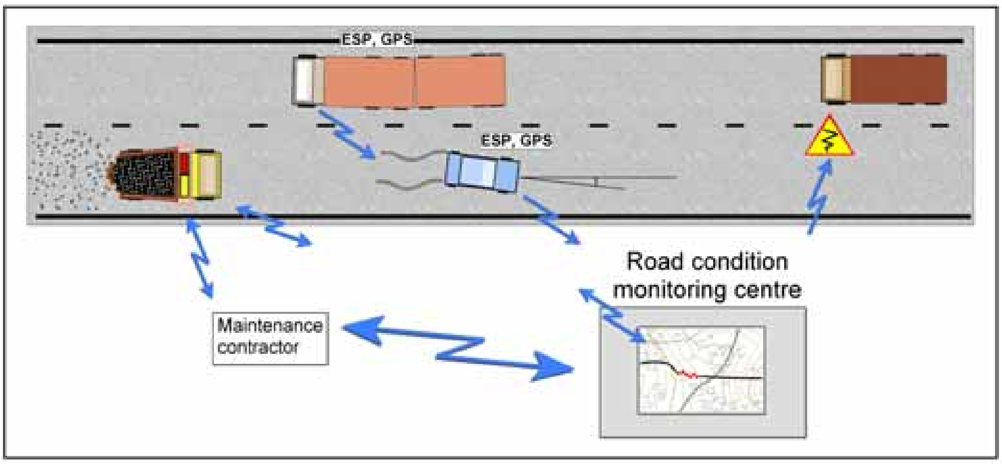

Figure 3. Illustration of a real time road friction monitoring system.

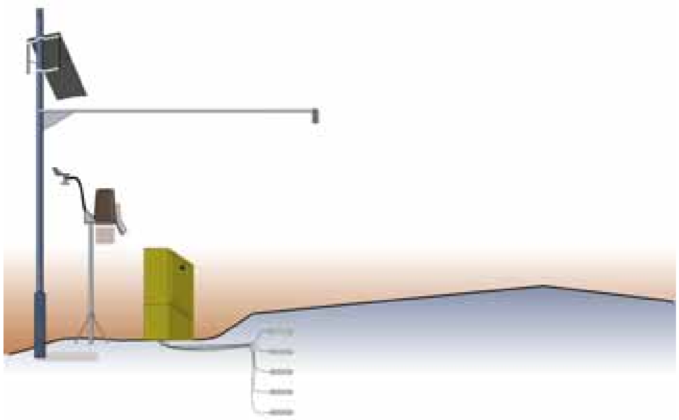

Figure 4. A schematic diagram of an integrated system combining a Percostation and a weather station for use on low volume roads. In addition to the parameters measured by the Percostation (see chapter 6.3), the weather station would measure temperature, wind, rainfall and evaporation and is also outfitted with a sensor for measuring snow thickness on the road surface. The system generates its own power through a solar panel and transmits data via a GPRS system.

In addition to reviewing real time monitoring techniques the ROADEX II project has been developing a new idea that could be further expanded to the benefit of winter maintenance management especially on low volume roads in remote areas serving timber haulage. It is a fact that more and more timber trucks have recently been equipped with under blades and sand spreaders (figure 5) because the timber haulage companies have taken more and more responsibility for the winter maintenance activities on forest roads.

Because timber is often being hauled via parts of the public road network that often hardly have any other road users. These roads, due to their low traffic volumes, are added to the end of the queue of winter maintenance measures – with the resulting irony that trucks, equipped with winter maintenance tools that they are not permitted to use, must travel on roads that have accessibility problems because they have not yet been cleared by maintenance crews. So if, for instance, during difficult snow storms timber trucks equipped with winter maintenance tools were also allowed to take measures on certain public roads that they are using this would allow maintenance contractors to concentrate on providing better service to the roads with higher traffic volume.

There are of course some obstacles to overcome since maintenance contracts are made between road regions and contractors, but new types of partnerships and modern information technology could certainly provide the answers to these problems with the end result being a win-win situation for all of the concerned parties. In this system, basically the same technology that is used in the freight management and spring thaw weakening management could be used.

Figure 5. Under blade mounted on a timber truck in Finland that is also used for winter maintenance of forest roads.

Chapter 4. Monitoring structural condition

Figure 6. Heavy rains can cause major erosion problems on low volume roads if the drainage system is not working well

The structural condition of a road is the most critical parameter when considering the asset value of a low volume road network. Neglecting the structural condition of a road has a major impact on the cost for road owners in the long term, but at the same time, a gravel road in poor structural condition, for instance, can cause immediate significant short terms problems with regard to accessibility during the spring thaw period. In addition, a drainage system in poor structural condition can also create sudden accessibility problems especially after heavy rains (figure 6).

The management of structural conditions is not however entirely a problem created by low level funding but road officials could also do several things differently in order to take better care of the road structures over the long term. One good example is to maintain the drainage at a higher level. The drainage report from the ROADEX II project (Berntsen and Saarenketo 2005) clearly shows that by keeping the drainage system in good condition it is possible to prolong pavement lifetimes by a factor of 1.5 – 2.5.

Improving structural conditions can also have positive effects in reducing spring thaw weakening problems and improving winter driving conditions as well as reducing winter maintenance costs. For example, raising the grade line of a road located on flat ground or in a low lying valley (see Saarenketo and Aho 2005, Norem 2001) reduces problems with the accumulation of snow due to drifting.

There are several parameters that can be used to describe the structural condition of a low traffic volume road. Each ROADEX partner country has an expression for describing structural condition that generally has the same meaning (*bearing capacity, bärighet, kantavuus*). The EU Cost 325 report defines "*Bearing capacity is a general concept that attempts to describe the ability of a pavement to support heavy vehicle traffic*". So the expression bearing capacity has a very broad meaning and it cannot be defined as one single number. Many things can affect the structural condition of a road: the source of a problem can be related to a) poor quality bound materials, b) poor quality or too thin unbound layers and c) weak subgrade soil – or the cause of problems can be simply d) poorly performing drainage.

In Finland bearing capacity of a road has been traditionally expressed as an **E2** value calculated from the FWD measurement data. The problem with this E2 value, originally used with static plate load testing systems, is that it is very dependent on the subgrade quality. For instance if bedrock is close to surface the E2 values are always good while road sections resting on peat get low E2 values even though the performance is good. That is why in project level evaluation and road analysis it is recommended to use Surface Curvature Index **(SCI)** describing the stiffness of the upper part of the pavement structure and Base Curvature Index **(BCI)** describing how the road can spread the load over a weak subgrade.

In Sweden new parameters have been developed to describe the bearing capacity of a road. This parameter "**bärförmåga**" is a function of calculated strain under the pavement and the number of standard axles on the road and is also a very good parameter for describing the pavement condition. Bärförmåga has been successfully used in Sweden in a network level analysis of the low volume road structural conditions in Region Mitt (Middle Region).

Perhaps the biggest problem with regard to the structural condition of low volume roads in NP areas is the weakening and permanent deformation of unbound materials and subgrade soils during the spring thaw periods (see Dawson and Kolisoja 2005, Saarenketo and Aho 2005). The **risk for permanent deformation** cannot always be monitored using traditional bearing capacity measurements methods in summer. It must be kept in mind that, for instance, if the E2 value or bärförmåga values are reasonable, the road may still have problems with frost and permanent deformation – but if these parameters are bad, then the road is always in bad structural condition. One parameter that has been found to be effective is the **dielectric value** of the unbound road materials.

Finally, a reliable means of detecting problems with structural condition is to analyse the increase in rut depth on paved roads. If the **rut development speed** is faster than average it may be as a result of deficiencies in structural condition.

The structural condition of a road can be measured in three ways (see Cost report 325). The first method is to measure the thickness of the road structures using a **Ground Penetrating Radar** (GPR) system, the second method is to measure the deflections from the road surface using different deflection testing methods, such as **Falling Weight Deflectometer** (FWD), and the third method is to evaluate the structural condition by monitoring the different types of **pavement distress** on the road. The last method can really only be used on paved roads and even then, when structural problems are identified, it is in many cases too late for sustainable road condition management measures to be carried out.

The ROADEX II project recommends that at least two parameters be added to the tool box above used to assess the structural condition of low volume roads: **drainage evaluation** and **Dynamic Cone Penetrometer** (DCP) method. The risk for permanent deformation of unbound materials can be evaluated by taking samples from the base course and then conducting **Tube Suction Tests** (TST) on these samples.

Descriptions of the above methods are given in detail in the ROADEX II report by Saarenketo and Aho 2005 and the COST report 325 (1997). Of these methods Finland routinely uses GPR, FWD, pavement distress analysis in network level evaluations of low volume roads. Drainage is evaluated on gravel roads and GPR is used in project level surveys of most roads. Sweden uses GPR, FWD, and pavement distress and drainage inventory in project level surveys. Norway uses the same techniques as Sweden in project level surveys except for the GPR technique. In addition, Norway has been successfully applying DCP in road surveys. Scotland does not yet follow a standard procedure for structural evaluation although in recent years they have been testing different methods of structural evaluation.

In Scotland, Forest Enterprise has also started a pilot project involving a network level evaluation of the structural condition of the forest road network (Figure 7). In these tests forest roads are surveyed with GPR and a portable FWD. IRI is also measured in some road sections using an accelerometer based IRI data collection system. At the same time as the GPR data is collected a digital video of the road is also recorded with the positioning done using a GPS system.

Another case of structural condition monitoring development in Scotland was a survey carried out in 2001–2005 to analyse the impact of timber transportation on the weak single-track roads B871 and B873 from Kinbrace to Syre. The goal for the project was to develop a reliable and cost effective evaluation system to predict the impact of heavy timber transportation on the low traffic volume roads with bearing capacity problems. This analytical system would then be used to produce a database that would allow selection of optimal maintenance and repair techniques for each road section keeping the public road serviceable during and after timber traffic. The results of this project, reported by Saarenketo (2005) were very encouraging and this risk analysis is now more widely used in different projects in NP area.

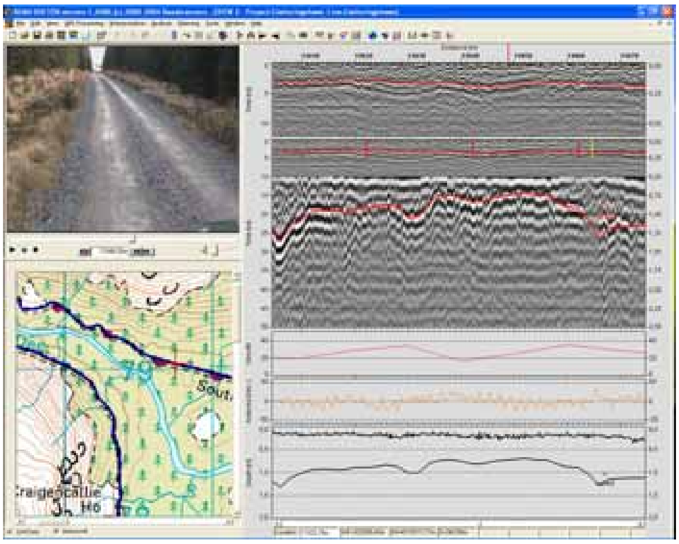

Figure 7. Structural and functional condition evaluation of a forest road in Scotland. The topmost profile presents the GPR data from the 2.1GHz antenna which measures base course and wearing course, if it could be identified. The second field presents combined 2.1 GHz GPR data (top 10 ns) and 400 MHz data (10 – 50 ns). The third field presents IRI data calculated in 10 m mean values and the fourth profile presents the distance from the air coupled GPR antenna to the road surface which is an indication of how much the survey car bounces as it travels the road. Big changes indicate big bumps. The lowest profile indicates the thickness of the road structures over the subgrade. On the left in the Road Doctor software user interface a digital video and a map of the section under survey is presented.

Chapter 5. Functional condition and its monitoring tools

The “**functional condition**” of a road is a summary of several individual elements that affect the drive comfort, health and safety of the people using the road. It also has a great effect on transportation costs of industries and products and thus on the economic life of rural areas. Poor road functional condition increases fuel consumption, causes time delays and can damage vehicles using the road.

The critical parameters that describe the functional condition of low volume paved roads are rutting, surface friction, longitudinal roughness, including bumps and potholes and wide longitudinal cracks. Drive comfort is also reduced by poor patching and undulating cross fall which can cause problems especially for heavy vehicles. With regard to gravel roads, washboarding of the road surface, dusting and surface firmness should be added to the above mentioned list.

Rutting, of all the functional condition parameters, can still be ranked as the most important parameter because of its direct effect on traffic safety. Another parameter that has a direct effect on traffic safety is **surface friction** (slip resistance). However in the NP area surface friction has not been a major issue mainly due to the use of studded tyres. In the Highlands of Scotland studded tyres are not common and surface friction has been handled by using surface dressing pavements.

The main parameter affecting drive comfort and aspects of road users’ health are the vertical acceleration values measured from the human body. Acceleration values from a human body are mainly affected by the longitudinal **roughness** of a road. Road surface roughness is composed of different wavelengths and, as such, driving speed also affects drive comfort and the amount of unhealthy vibrations on the human body. High and uncomfortable roughness values are mainly caused by differential frost heave bumps but also potholes and sharp cracks.

The most popular parameter used to describe the roughness of a paved road has been the International Roughness Index (IRI). However recent tests in Sweden have shown that IRI values might not be the best indicator for drive comfort on low volume roads and that **vertical acceleration** values could be much better indicators. Also the problem with IRI values, particularly on gravel roads, is that they cannot be measured reliably using laser sensors. ROADEX III will focus these issues under guidance of Johan Granlund.

The research results from the ROADEX Phase I professional road user interviews and from the Finnra S14 project (Lämsä and Belt 2004a), studying drive comfort, have drawn quite similar conclusions which seem to be in contrast with the standards that the road administration follows with regard to maintaining functional condition. In both surveys, the conclusion has been that, from a road user’s perspective, the most important parameters to consider when examining the functionality of a paved road are uneven frost bumps and potholes.

An important factor, when discussing drive comfort as well as health and safety factors, is that traditionally rutting and roughness values have been described in 100 – 400 m mean values. When these average values from long sections are used there are many cases where a single and uncomfortable uneven bump located in a section of an otherwise even road will be ignored (see figures 8). Test results clearly show that when 100 m mean IRI values are used it is impossible to detect those sharp bumps that heavy vehicle operators consider to be extremely intolerable.

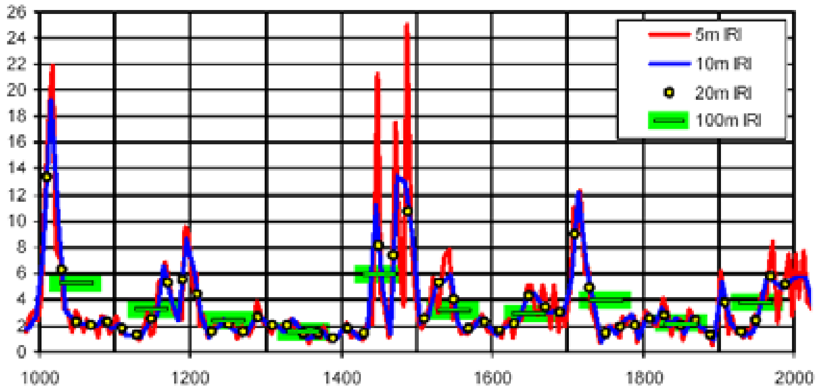

Figure 8. IRI values measured from a poor quality low volume road, Road 8250, section 2 near Oulu and calculated in mean values of 5 m, 10 m, 20 m and 100 m. Figure is modified from Lämsä and Belt 2004a.

Roughness and rutting of the paved roads as well as cross fall is mainly measured using **laser profilometer** techniques. On low volume roads cheaper systems, utilising **accelerometers,** mounted on the rear axles of a vehicle can be also used. Accelerometers are the best sensors to measure roughness on gravel roads. Sweden will be testing ideas where accelerometers are installed on postal vans that routinely use the low volume road network (figure 9). However, thanks to development of the **car tyre sensor** technology, new intelligent tyre systems can detect changes in the tyre and, based on these changes, roughness parameters can be calculated. This means that roughness measurements can be done, in the future, by standard passenger cars.

Currently, there are also several research and development projects trying to develop **laser scanners** to prepare a 3d model of the road surface. With these models it should be possible, in the future, to calculate road surface parameters. Other techniques that are currently available are **automated pavement distress monitoring** systems. Pavement distress and washboarding, potholes and dusting on gravel roads have traditionally been monitored visually from a moving vehicle, but recently some organizations have begun to analyse these parameters through the use of digital **video** which provides more reliable and repeatable results.

Detecting of vibrations from the roads surface

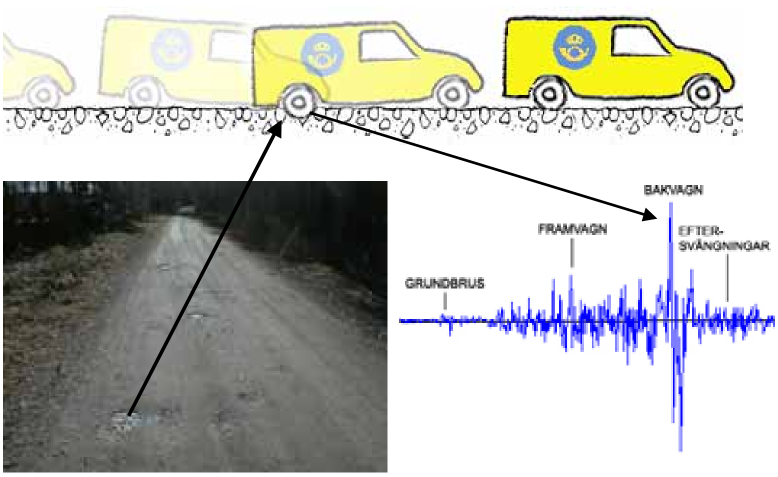

Figure 9. Swedish gravel road monitoring system where accelerometer sensors are installed to post vans that are daily using the road network. Figure is from Johansson et al. 2005.

Chapter 6. Spring thaw weakening monitoring

Freeze-thaw cycles and spring thaw weakening has been identified as being one of the most difficult problem areas of low volume road condition management in the ROADEX area. A major part of the damage develops on roads during the spring thaw and better management of these problems can more than double the lifetime of the low volume road network in the Northern Periphery. Preferably, this should be accomplished without the use of load restrictions and with minimal impediment to the haulage industry. Spring thaw weakening and load restrictions policies as well as monitoring techniques are discussed in more detail in the ROADEX II report "Managing spring thaw weakening on low volume roads" by Saarenketo and Aho (2005).

Due to the complex nature of spring thaw weakening there are several critical parameters that should be monitored in a modern spring thaw management system. In general the monitoring areas can be divided into three main categories: a) weather and temperatures affecting road structures and subgrade soils (freeze-thaw), b) moisture content, stiffness and risk for permanent deformations, and c) information regarding heavy traffic. In an optimum system, parameters in all these categories should be monitored.

Frost depth and **soil temperature** are the most popular meteorological parameters used to indicate if the materials are frozen or thawed. The ROADEX II project results have shown that **daily rainfall** is also an important parameter, especially in Scotland, when monitoring risk for road failures after freeze-thaw cycles. Also **evaporation** is likely to become a very useful parameter in the future, especially on gravel roads.

The second category consists of "engineering parameters", of which the most important parameter is the **volumetric water content** (free water) of road materials and subgrade soils. The best parameter for describing the volumetric amount of free water is **dielectric value.** Other important parameters, but more difficult and expensive to monitor, are the parameters related to stiffness of the road structures and subgrade soil (**modulus and CBR**) and parameters, such as **electrical conductivity**, that can be used to evaluate the risk for permanent deformation. The level of the road surface due to **frost heave** and **thaw settlement** can also be a useful parameter.

Finally, the third category of parameters provides information regarding heavy traffic with the most popular parameters being the **axle loads** and **total weights** of heavy vehicles. The results of the ROADEX II project show that the time intervals between heavy vehicles and the subsequent **road recovery times** are major consideration when trying to prevent road damage during spring thaw. A very interesting and potentially new idea to monitor spring thaw weakening is to measure the **rolling resistance** of a truck. This could be done through modern truck computers measuring fuel consumption and an Air Spring Weigh Sensor System (ASWSS) measuring truck load. On weak roads rolling resistance is high due to high deflections under the vehicle tire and comparing the data from the stiffer summer months can provide continuous information concerning areas of risk.

Of all the current spring thaw weakening monitoring methods **Visual Inspection** is the most popular. However this is a very subjective method and of the ROADEX partner countries only Finland has a systematic approach to visual monitoring of spring thaw weakening damage and storing this information in databases.

Another area of interest has been to monitor frost depth. In the 1980´s and early 1990´s frost depth was monitored in many countries using the so called “**Gandahl tubes**” installed in the road or, as in Finland, in the paved parking areas of road maintenance bases. However this and other types of frost tubes broke quite easily and the data collection was labour intensive and as a consequence this method is no longer widely used. If the goal is only to monitor whether or not the road structures and soils are frozen, one of the best methods is to install **temperature sensors** at close spacing in the road and subgrade soil. Another method has been to use sensors that **measure electrical conductivity** or resistivity. This is based on the fact that soil becomes electrically resistive when it is frozen.

Dielectric value can be measured using **Time Domain Reflectometer** probes (TDR) or probes that detect changes in **electrical capacitance.** Dielectric value of materials can also be monitored through the use of special **Ground Penetrating Radar** (GPR) sounding techniques. The best results are obtained if a number of parameters are monitored simultaneously. In the ROADEX II tests sites, the **Percostation** technique was used to measure dielectric value, electrical conductivity and temperature at the same time (figure 10).

The stiffness of road structures and subgrade soils during the spring thaw period can be monitored through the use of **Falling Weight Deflectometer** (FWD) or **Dynamic Cone Penetrometer** (DCP). The FWD data, especially when collected at different load levels, provided valuable data in the ROADEX II tests. The DCP method demonstrated itself to be a tool with a great deal of potential because it is both cheap and easy to use and, in addition to giving data on stiffness, it also can provide information concerning the frost depth (Saarenketo and Aho 2005, Aho et al. 2005).

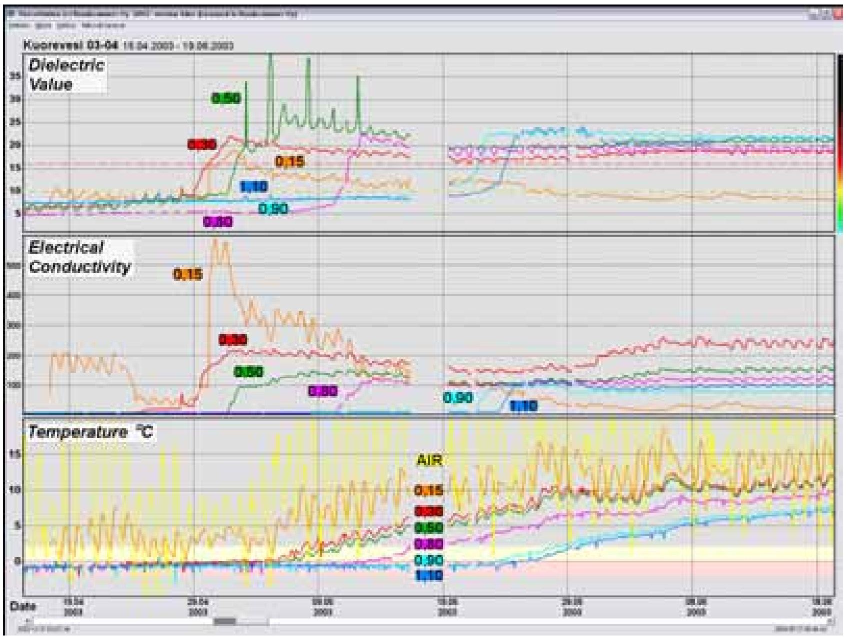

Figure 10. Monitoring results from Kuorevesi Percostation during spring thaw period in 2003. Each colour represents sensor readings from different depths.

Chapter 7. Freight monitoring

Freight management monitoring using sensors technology and modern wireless information technology has been developing rapidly in recent years. New freight management systems have been implemented especially in Central Europe (Conway and Walton 2005) but these techniques also have great potential for managing transportation and loads in the rural areas of the Northern Periphery.

There are several techniques that have been tested that could be used in weigh in motion (WIM) systems on low volume roads. In the ROADEX II partner areas, only Sweden has carried out extensive testing with WIM systems and the SiWIM system is already in routine use (VV Publ 2003:165, Saarenketo and Aho 2005). The most commonly used WIM sensors are based on the technologies of bending beams, piezoelectric sensors and single load cells. In addition to these, new sensors have been developed, of which those with the greatest potential are quartz sensors and fiber optic sensors (Conway and Walton 2005).

Automated vehicle identification (AVI) systems have also been developed in recent years and primarily because of the implementation of user fees on heavily trafficked motorways in Germany and Switzerland. On the first of January 2005, Germany started full operation of a GPS based toll collection system. Carriers using the automated systems must first equip their trucks with an OBU system available free from Toll Collect. Once the system has been installed it uses GPS technologies to recognize when trucks are driving on toll roads and calculates the distance traveled (Conway and Walton 2005).

Of all the remote and on-board monitoring system technologies perhaps the most promising system for low volume road management would be a combination of freight management systems with a truck weight monitoring system, using air-spring suspension weight sensors, and a central tire inflation (CTI) system that can monitor tires pressures. When these systems are connected to the automated vehicle identification systems this allows road users and road owners alike to monitor loads and loadings in real time and this system has especially great potential for managing spring thaw weakening (Saarenketo and Aho 2005).

Chapter 8. Focusing on the road users needs

The needs of road users will have an ever increasing influence in the road condition management of low volume roads. These needs can be roughly divided into three main categories: a) safety, b) accessibility and c) specific (structural and functional) problems.

Naturally safety is the primary issue for road users on low volume roads. According to the ROADEX road user need survey (Saarenketo and Saari 2004) the main traffic safety concerns for road users in the Northern Periphery are related to poor winter maintenance standards and operations but in Norrway the risk for avalanches is also a critical issue. But the worst safety scenarios were reported on roads where poor winter driving conditions occurred in road sections with other problems, such as uneven frost bumps, steep hills or tight and narrow curves.

After traffic safety, “accessibility” or “regularity” is the second greatest priority. In the Northern Periphery area, low volume roads accessibility problems are mainly related to winter maintenance where snow storms or avalanches block the road. Another major accessibility problem is caused by spring thaw weakening especially on gravel roads in Scandinavia. Finally erosion after heavy rains and flooded rivers cause problems every now and then. All of these problems should be evaluated when making a risk analysis before preparing maintenance standards for a procurement policy.

Once major traffic safety and accessibility risk have been addressed the remaining resources available for the low volume road condition management should be directed towards specific problems for each road and area. These problems could be either structural or functional problems as described earlier in this report. In order to get the best value for the investment these measures should be focused on those sections causing the biggest problems for road users. The ROADEX road user survey (Saarenketo and Saari 2004) along with other surveys regarding drive comfort on low volume roads have shown that bumps and potholes cause the greatest discomfort for road users.

In the new ROADEX II proposal for low volume road policies (Johansson et al. 2005) the information collected from the road users has a very important role in defining the service level and maintenance trigger values when developing procurement policies. In this proposal, the road user needs are first surveyed by estimating the transportation needs of both people and businesses. These results in combination with assessments of lifeline roads and the fragility of each area are used to calculate a “Transportation Need Index”.

Following up road users’ opinions and feedback is also an extremely important aspect of successful road condition management of low volume roads. The ROADEX road user interview survey clearly showed that when road users felt that their opinions were appreciated and were considered in the management of the condition of the road their ratings of a particular problem were more positive than would have been expected. A good follow up system is also needed in order to be able to improve procurement policies, as well as the standards used for maintenance contract bonus systems which are based on the level of road users’ satisfaction.

Traditionally road user needs and opinions regarding road condition have been monitored through periodic questionnaires and interviews. The problem with these questionnaires, however, is that they mainly provide information concerning the general trends in road users' opinions and not much in the way of detailed information required to assess "project level" needs. However, the road user survey carried out in the Phase I survey of the ROADEX II project (Saarenketo and Saari 2004) also produced useful information indicating the locations that road users felt were problematic or where they were not generally happy about the condition of the road. In this survey, the road user could mark the problem areas on a map and give written comments concerning detailing the problems. Figure 11 provides an example of one such map from the Island of Senja, in Norway, where road users have indicated where the road is in poor condition in the summer.

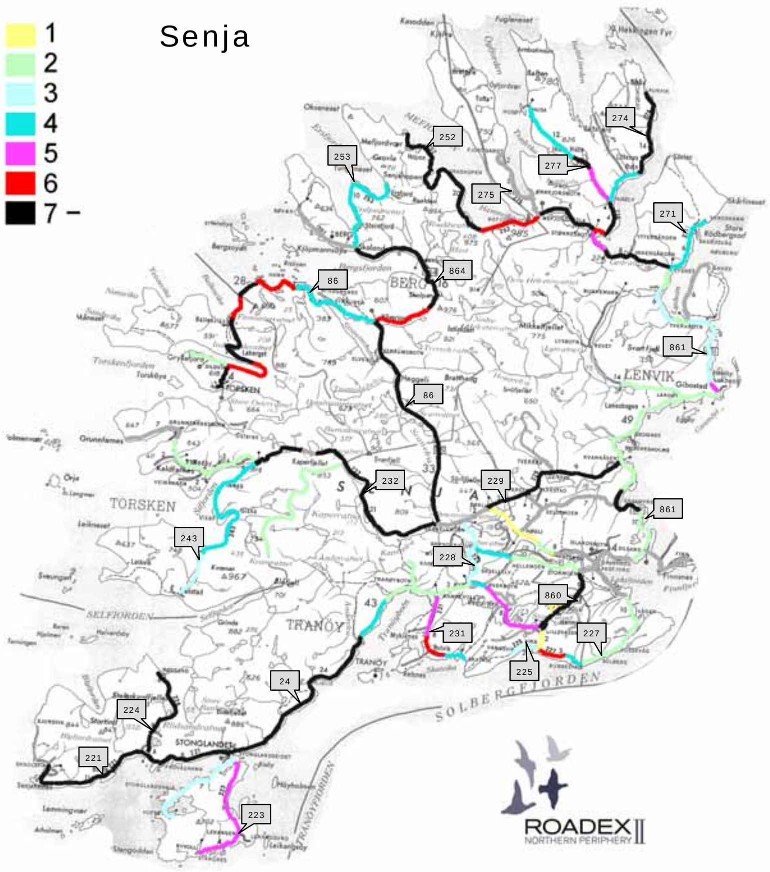

Figure 11. Professional road users' opinions on the location of problem roads in summer on the island of Senja in Norway (Saarenketo and Saari 2004).

However these kinds of questionnaires are expensive to make for this purpose alone. One way to spread the costs would be to have these questionnaires done in conjunction with the customer satisfaction studies used to award bonuses to regional maintenance contractors. The Finnish road administration has recently developed and tested regional customer satisfaction surveys in five areas (Sarkkinen et al. 2004).

Chapter 9. Focusing measures on the correct location

Knowing the limited resources available for low volume road condition management in the Northern Periphery, one of the key principles for improving the condition of the road network is to focus all of the maintenance and strengthening measures on only those sections that need them. Modern positioning technology and information systems as well as automated road construction machinery development with capabilities of handling large amounts of data allow road engineers to focus precisely on the road sections needing better maintenance or rehabilitation actions and define the optimum measures for these sections. If systems are to be improved there should be a clear change in thinking from the current philosophy of using 20 – 100 m section modules down to 1- 10 m modules.

However in order to create a better focused system the whole road condition management process needs to be upgraded to a level where it can handle more accurate information. For example, it does not make sense that design systems continue to work in 20m sections when GPR can provide data with 1 m accuracy. Some of the key factors and modules needed for better focus are discussed in the following:

<u>Road referencing system, Road registers</u>
Even though GPS (Global Positioning System) will be a key component in the future and almost all of the positioning information will be based on GPS coordinates, there will be always a need for a road or route referencing system (also called as road registers) where the road network is organized into roads which are further divided into sections, subsections and lanes. These systems utilise a special road address system that also has GPS coordinates to which all of the numerical data collected from the road can be linked. Furthermore if someone is searching for information from the system then either road addresses or coordinates can be used. Then when road specific information is sent to road users this information will be based on this referencing system.

<u>Road survey and monitoring systems</u>
The key issue when moving towards highly focused road maintenance and rehabilitation systems is finding road survey systems that can collect and store road condition data at short distance intervals but that also have precise positioning systems. In these continuous surveys the key tools are GPR systems, profilometers and digital videos. In the future there could also be automated pavement distress analysis and moving deflection measurement units that could be useful in the collection of data. Laser scanners that reproduce the surface form of the road are also being developed and will be of great help when they can also be used economically on low volume roads.

<u>Data storage</u>
Road owners must have new types of data storage systems that allow all of the different data types and formats collected from the road to be stored at the original level of accuracy and quality. Traditional Pavement Management Systems that have been designed to handle the data on a national level are not suitable. The new systems of module based data bases allow the storage of big data files in a single

data base module, from where it can be unzipped and analysed whenever needed. In the future these systems will not have to be operated by the road owners and the trend is that road authorities will purchase these services from specialized service providers. However, experience from many countries has shown that it is very important that road owners maintain ownership of all the data that is stored on these systems.

Software and data formats

In order to be able to analyse all of the data collected from the road there is a need to have software that is capable of reading different types of data from different data bases and data storages, processing and analysing it on an integrated basis so that engineers and contractors can easily get a good overview of the conditions and problems in each short section. Because the data will also be downloaded and used in design systems and, in the near future, automated machinery working at a site, all of the software will have to produce open and standardised data transfer formats. New infra product model projects currently under work at least in Norway and in Finland will most likely solve these problems.

Positioning and referencing systems

An extremely important issue when moving towards more focused road measures is to have positioning and referencing systems that are common and precise enough so that everyone participating in the process is working to the common system and can easily check locations. A good example that emphasises this issue comes from Finland where one of the major causes of failures of a repaired spring thaw damage sections was that the contractor constructed the repair structures in the wrong place due to poor positioning and referencing.

In general positioning systems for low volume road condition monitoring, design, maintenance and rehabilitation systems can be divided into four classes:

1. Positioning systems based on the measuring distance from a known reference point (DMI, trip meters)
2. Positioning systems that are based on Tachymeters (optical systems)
3. Positioning systems based on linking the data with digital photos or videos from the surveys site
4. Wireless electronic positioning systems such as GPS

The future of the positioning systems will definitely be based on wireless electronic positioning systems but the best systems will be those that apply more than one of the above mentioned techniques. ROADEX II monitoring report (Saarenketo 2005) will provide more detailed description of these positioning techniques and their future trends.

Chapter 10. Designing monitoring systems

When designing monitoring systems directed at the improvement of road condition management on low volume roads there are several factors that one needs to be aware off. First of all, the problem definition, i.e. what **type of problem** needs to be solved/monitored, has to be made. On low volume roads the potential problems could be: a) monitoring functional road condition including winter maintenance parameters, b) monitoring structural condition of the road, c) monitoring spring thaw weakening or freeze-thaw cycles, d) monitoring vehicles, their speed, axle loads and total weights, e) monitoring road users needs or f) quality assurance monitoring of contractors work. A good low volume road condition management system should somehow monitor all of these parameters.

After the problem is defined the following factors need to be evaluated: a) Sensor type and amount, b) Location of sensor installation, c) Data collection density, d) Positioning (especially when using moving vehicles), e) Data transfer, f) Data storage and processing, g) Implementation of the data and decision making system, h) Information system.

Once the problem has been defined the type of sensors can also be defined when a place for their installation is selected. Basically, sensors can be installed in: a) road structures or road surface, b) bridges, c) cars or trucks, d) aircraft or satellites or e) sensor can be carried. In addition there is also the recent innovation of installing sensors on tyres which is an inspired idea since tyres are in direct contact with road surface.

The data sampling and data collection rate can be based on either length or time depending on whether the sensors have been installed in a static emplacement or mobile platform like a vehicle. When moving towards more focused systems the data collection density must also be higher.

A reliable positioning system is a key component of a successful monitoring system. In a stationary monitoring system this is obviously not a problem but with mobile platforms positioning has to be done correctly. In a well designed system this is often ensured through the use of double or triple systems, which means that the collected data is positioned using for instance GPS data, DMI data (Distance Measurement Instrument, trip-meter) and digital video frame links

Data transfer techniques depend mainly on how great the need is to have the data immediately available for analysis. Stationary sensor systems can send information through telephone lines or GSM/GPRS modem connection. When sensors are mounted on a mobile platform the most popular systems are to record survey data on hard drives and then download the data when the vehicle returns to the office. In cases where sensors are used to guide winter maintenance actions, in the future, the data will most likely be transferred to monitoring centres only when certain alarm values have been measured. Also if, for instance, truck weights are monitored using systems like ASSWS the system always weighs the truck load when the truck stops and then sends the results along with positioning information.

All the data collected in the field has to be properly organized of course. This is especially the case when collecting functional or structural data. The national pavement management systems (PMS) in each Northern Periphery country have a proper system for storing the data but unfortunately this data is, frequently, not suitable for use in highly focused low volume road measures.

The future monitoring systems will not be effective if they are not followed by an efficient decision making systems. This could be the most “painful” part of the whole process. Within the administrations the decision making process can involve a number of meetings and legislation may require more than one signature for each document all of which can take time. But the effectiveness of these systems is often based on how fast decisions can be made and this can, in some cases, save lives and with that in mind this issue should be examined carefully and the decision making processes redesigned.

Finally a key aspect of a well functioning system is the dissemination of information and decisions regarding monitoring results or maintenance measures to the interested parties. Traditional information systems have utilised letters, faxes, newspapers or radio and television, but current modern information and communication technology enable the innovation of more advanced systems. In the future, two very important system resources will be the internet and wireless communication systems designed to provide information to and from road users, maintenance contractors and road owners. Figure 12 present an example of such a system already in use in Finland for monitoring maintenance measures.

With regard to low volume roads, systems that have been designed to warn drivers of traffic jams could be also used to provide warnings related to difficult winter driving conditions in certain areas, avalanches or even just a dangerous bump ahead. During the spring thaw period it could also be formatted to display roads with load restrictions or where the use of CTI techniques is mandatory.

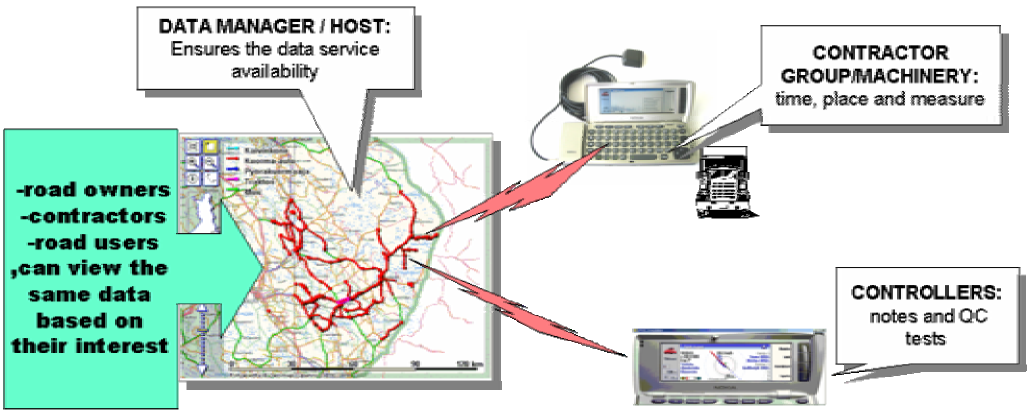

Figure 12. A description of information systems used in Finnra maintenance contracts in Finland. System consist of web based GIS data base system that is hosted by data manager service provider. Contractors inform all the maintenance measures trough wireless links to data manager where road owner can analyse them. In addition controllers can check in place if the measures were done correctly. Also road users can view certain data fields. Figure modified slide provided by Markku Tervo 2005.

Chapter 11. Summary

This report presents both the current and future technology, as well as ideas, for monitoring systems that could be used in low volume road condition management in the Northern Periphery area. The main advantage of these systems is that the data allows road owners and/or contractors to focus their maintenance and rehabilitation measures on an exact spot, improve the timing of measures and also select an optimum measure for each location. This report also presents new ideas and innovations that could be used to solve or minimize some other low volume road management problems that have been identified in the ROADEX project.

These new technologies can be used in the following key fields: improving drainage, improving structural condition, improving functional condition of the road network, better freight management and spring thaw weakening management, improving winter maintenance practices, improving gravel road maintenance and finally improving possibilities for road users to participate in the road condition management process.

The ROADEX II project phases I and II have produced much in the way of valuable basic information which can be directly applied towards developing better road condition management but this information, if it is used together with modern sensors and telecommunications technology, can open a totally new possibility of improving the condition of low volume roads too. The future trend is that, most likely, the work of monitoring road conditions will change from tasks carried out by specialized data collection vehicles to a system where cars that routinely use the low volume road network will be utilized as sensor platforms instead. In this way, a greater area will be monitored at a higher frequency and at a lower cost. Figure 13 describes the future playing field of monitoring and managing low volume roads in NP areas.

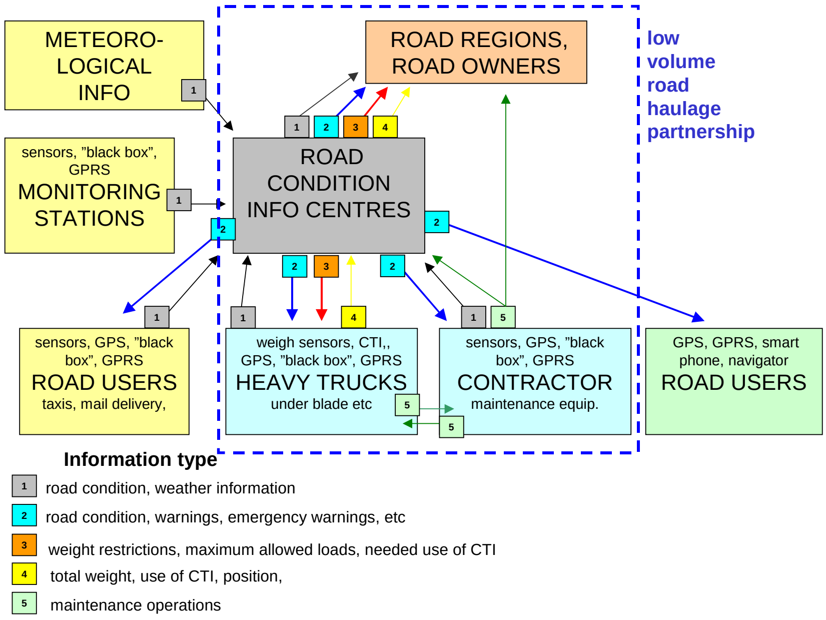

Figure 13. Future playing field of monitoring and managing road condition on low volume roads in the NP area.

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