Timo Saarenketo

MONITORING, COMMUNICATION AND INFORMATION SYSTEMS & TOOLS FOR FOCUSING ACTIONS

Ideas and Innovations

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April 2005

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Roadscanners Oy

PREFACE

This is a final report from the Phase III subprojects 3_2 and 3_4 survey of the Roadex II project, a technical transnational cooperation project between the Highland Council, the Western Isles Council, and Forest Enterprise from Scotland; the Northern Region (formerly Troms district) of the Norwegian Public Roads Administration and the Norwegian Road Haulage Association; the Northern Region of the Swedish National Road Administration; and from Finland the Regions of Central Finland and Lapland of the Finnish Road Administration, as well as Metsähallitus Region of Eastern Lapland, the Forestry Centre of Lapland (Lapin Metsäkeskus), Stora Enso and Metsäliitto, Procurement Area of Northern Finland. The Roadex project is partly financed by the ERDF IIIB Northern Periphery Programme. The lead partner in the project is the Highland Council from Scotland and the project consultant is Roadscanners Oy from Finland. The Roadex II project Chairman is Ron Munro from the Highland Council and the project manager is Timo Saarenketo from Roadscanners.

The report summarizes the current and future monitoring and sensor technology and presents ideas for new monitoring systems that could be used in low volume road condition management in the Northern periphery area. The main advantages of these systems are that the maintenance and rehabilitation measures can be focused exactly on the correct place. The Methods also allow better timing of measures as well as providing good basic information for problem diagnosis and selection of an optimum measure for each location.

This work is based on a literature review and web search as well as many discussions with experts in the field of road condition management, sensors technology and monitoring techniques. The author would like to thank the Roadex II project Road Condition Working team, Andrew Dawson, Geir Berntsen, Ralph Schackleton, Ron Munro, Johan Ullberg, Svante Johansson and Pauli Kolisoja for the valuable discussions and input for the report. In addition the following persons have given information and ideas for the report: Harri Eskelinen and Timo Mäkelä from Testworld Oy, Johan Granlund SNRA, Production, Anssi Lampinen, AL-Engineering Oy, Wave Tyrrel, Forest Enterprise, Lars Persson SNRA, Ilkka Lilja ILOy, Seppo Kosonen, Markku Tervo and Kari Parikka Finra, Marko Kallovaara Incode Oy and Curtis Berthelot PSI, Brian Taylor IRD.

This report has been written by Timo Saarenketo. Ron Munro from Highland Council and Saara Aho from Roadscanners have given valuable comments on the text. Virpi Halttu has edited the report, Kent Middleton has checked the language and Jaakko Saarenketo has given valuable help with graphics, all of the aforementioned people are from Roadscanners.Finally the author would like to acknowledge the Roadex II Steering Committee for its encouragement and valuable guidance in this work.

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ABSTRACT

The ROADEX II Project is a co-operation aimed at developing ways for interactive and innovative management of low traffic volume roads in the Northern Periphery Area in Europe. This survey has followed the Roadex II Project phase III theme of “ideas and innovations” by presenting new sensor, information and telecommunication technologies to monitor and improve road condition on low volume roads. The main advantage of these systems is that the data allows road owners and/or contractors to focus the maintenance and rehabilitation measures on exactly the right place, improve the timing of the measures and also select an optimum measure for each location.

The report begins with a presentation of the key areas of low volume road condition management that require different monitoring techniques. It also presents critical parameters that should be monitored in each area along with the techniques used to measure them as well as the consequences for road owners and road users if they are neglected. The report also describes parameters and tools for monitoring winter condition, structural condition of the road, functional condition of the road in summer and how to monitor spring thaw weakening and heavy vehicle weights. Ideas are also published on how road user needs, opinions and problems with regard to the condition of low volume roads could be monitored.

This is followed by a discussion of positioning systems which are the most critical issues when moving towards better focused measures on low volume roads. The report describes both positioning and data transfer techniques that are available or that will be available in the near future.

A description of the factors and problems that need to be solved when designing a monitoring system is also given in the report.

Finally, some ideas for interactive low volume road condition management systems are presented. The new way for an effective management system for low volume roads is to establish new types of partnerships where vehicles owned by local road users will be equipped with sensors that will be used to monitor road conditions and transmit real time information about any problems if the data warrants it. Another type of new partnership that should be considered is a partnership between road owners, maintenance contractors and road haulage companies directed at managing problems caused by spring thaw weakening.

This report also presents many new ideas and innovations that could be used to solve or minimize some problems that have been identified in the Roadex project.

KEY WORDS: Roadex, low volume roads, road condition, monitoring techniques, sensor technology, wireless information technology

1 INTRODUCTION

1.1 ROADEX II PROJECT

The ROADEX II Project is a co-operation aimed at developing ways for interactive and innovative management of low traffic volume roads in the Northern Periphery Area (figure 1). One of the major goals of the Project is to strengthen and reinforce the first ROADEX technical exchange and co-operation that was established in the Northern Periphery during the years from 1998 to 2001.

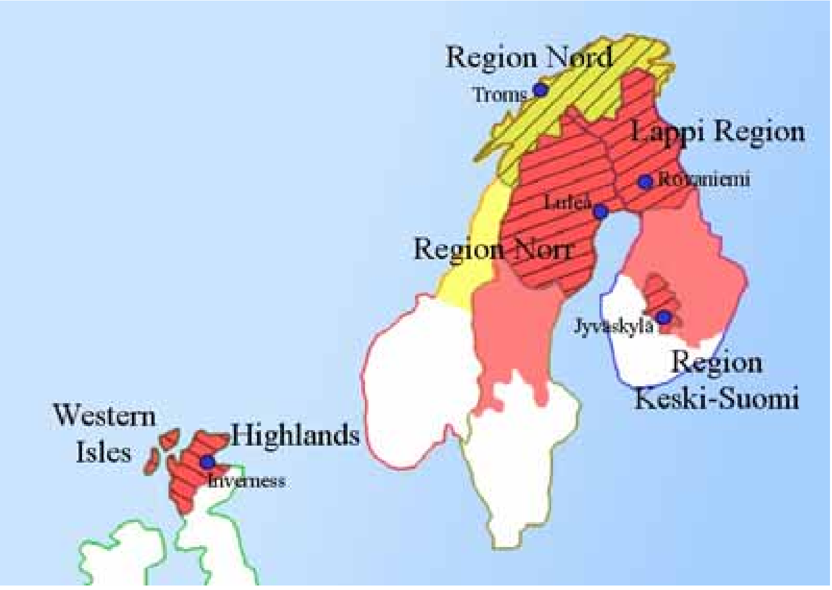

Figure 1. Northern Periphery Area and Roadex II partners.

Within this overall strategy the specific objective of ROADEX II was to develop ways for interactive and innovative road condition management of low traffic volume roads integrating the needs of local industry, Road Districts and society at large. This goal involved developing models, assessment methods and tools to improve local Road District road condition management taking into account the views of road users.

The partners within the Project comprised public road administrations, forestry organizations, forest companies and haulage organizations from the following regions in the Northern Periphery of Europe: The Scottish Highlands and the Western Isles, the northern regions of Norway and Sweden, and the regions of Central Finland and Lapland in Finland. The Roadex cooperation maintains a web site at www.roadex.org.

The Roadex II project was conducted in three phases during 2002-2005: (I) Problem identification, (II) Understanding and Analysis, and (III) Innovation and Testing.

The goal for the phase I work was to provide a road user's perspective on the condition of the road network in each test area. These areas were chosen to be representative of each partner road district. The survey focused on road users´ transportation needs and opinions on the general condition and trend of the road network in summer and winter, traffic safety issues, types of problems encountered with transportation industries as well as opinions regarding the level of cooperation with local road authorities.

Phase II focused mainly on the technical details of road condition problems shared throughout the regions. These problems, identified in the Roadex I project, included the permanent deformation of low volume roads, material treatment techniques, drainage problems, spring thaw weakening and its management, and managing road sections resting on peat. The phase also included a subproject that focused on the problems that would arise if low volume roads were allowed to continue to deteriorate. A final subproject evaluated current environmental guidelines for low volume roads through all the partner districts and produced a common environmental checklist.

The final phase of the Project, Phase III, will focus on preparation of proposals on which to base new low volume road condition management policies suitable for Northern Periphery areas. It will also summarize the findings of the phase I and II results in the form of new structural innovations and best practise methods. Finally phase III will briefly review the possibilities that modern information technology can provide for low volume road condition management.

1.2 New technologies to improve the focus on low volume roads

The reality concerning future low volume road condition management policies in the NP area seems to be that there will not be any major increases in government funding for these roads. As such, new technologies play a key role when maintaining and improving the aging low volume road network in the area. The productivity of investments must somehow increase; the key to answering this challenge is to improve focus. An 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 rapid development of modern sensor technology and when this is finally combined with the new positioning techniques (GPS) and wireless communication and information technology, it will provide numerous opportunities for using these technologies in low volume road condition management. Especially new sensors that can be installed on vehicles that use the rural road network on a daily basis are generating a number 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 concerning road condition, vehicle loads, traffic safety hazards etc. and then transmit the data for further processing and analysis – and, if necessary, this information would be sent to local maintenance crews and road users.

2 MONITORING AREAS

In Northern Periphery area, low traffic volume road condition management can, in general, be divided into four critical areas with each having special problems that require special monitoring techniques and measures. These four areas are winter maintenance, handling functional condition of the road in summer, handling 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 to these main areas 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 also be discussed later in this report.

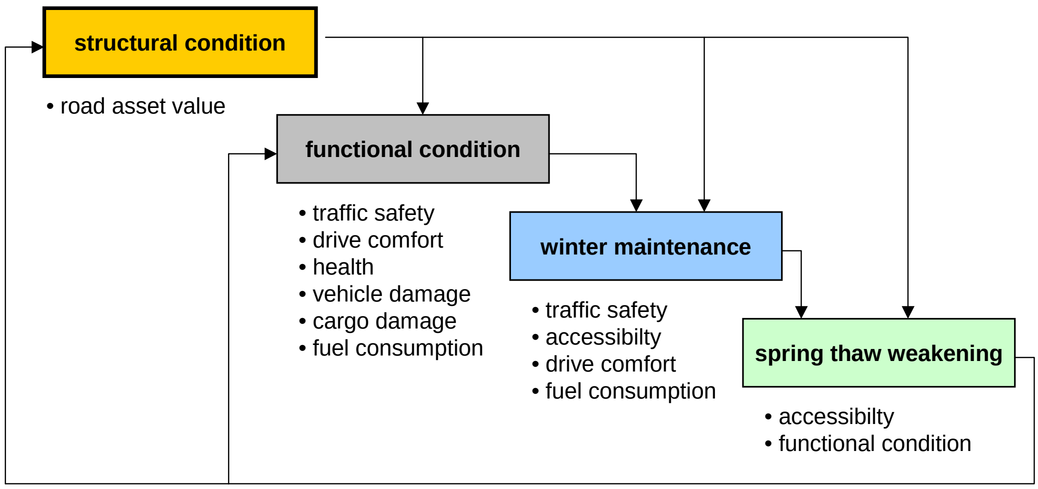

Figure 2. The main road condition management areas in Northern Periphery, their internal relationships and the main concerns for road owners.

Table 1 tries to summarize 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 in this management field are not done 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 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"	<u>All roads</u> -longitudinal roughness -friction -bumps -rutting -potholes <u>Gravel roads</u> -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 measurements -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

3 NEW WINTER MAINTENANCE MONITORING TOOLS AND PRACTISES

3.1 General

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 have been discussed during the Roadex II project and that could be used on low volume roads are presented in the following paragraphs. Some of these techniques could be integrated with other road condition monitoring techniques, such as spring thaw weakening monitoring stations.

On the low volume road network there are always difficulties with reacting in time to winter driving conditions that are becoming worse. Weather forecasts, weather stations and weather monitoring systems provide, in most cases, 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. Some of the ideas are described in the following.

3.2 New monitoring techniques and monitoring ideas

3.2.1 Real time friction control, maintenance guidance and road user warning

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. If the aforementioned systems are also supplemented with steering angle sensors, yaw-rate sensors and lateral acceleration sensors then these systems could be used to provide extremely valuable information regarding winter driving conditions. These inputs form a picture of what the vehicle is actually doing, which can then be compared with what the driver has actually attempted to do (see John Carey, www.arjeplogtestcenter.com/articles/).

With this idea in mind, then school buses, taxis and postal vehicles, for instance, could be further outfitted with 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.

This system alone may not make sense but as a component within a larger monitoring system, the application becomes practical and economical.

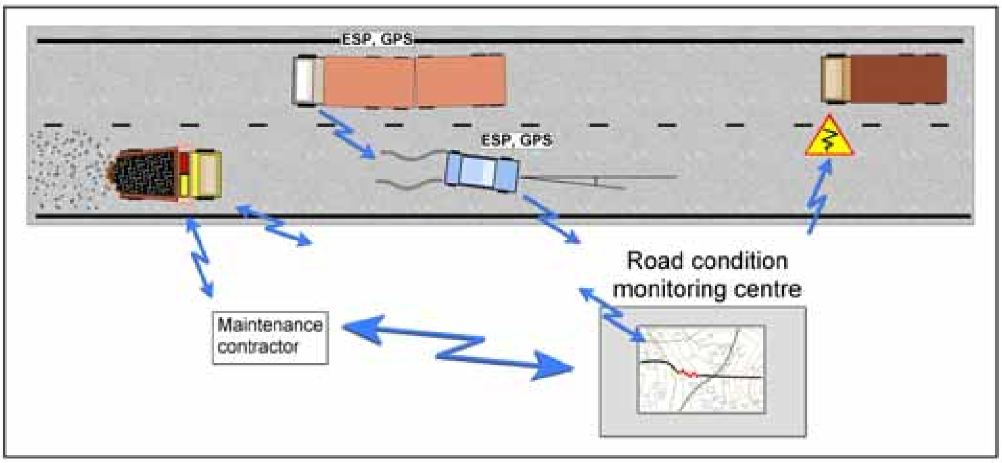

Figure 3. Illustration of a real time road friction monitoring system.

3.2.2 Other sensor and monitoring techniques

Other new technologies that could be used in low volume road condition management are modern weather stations and snow depth sensors.

Weather stations have traditionally been installed only on main roads because of their high price and their 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 station so that rainfall and evaporation could be monitored (figure 4).

Another technology that has become available for use on low volume roads is ultrasound sensors that can measure snow thickness. These sensors have become more reliable and cheaper (roughly 1000 euro/sensor) and have been used with success at airports in Finland. 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.

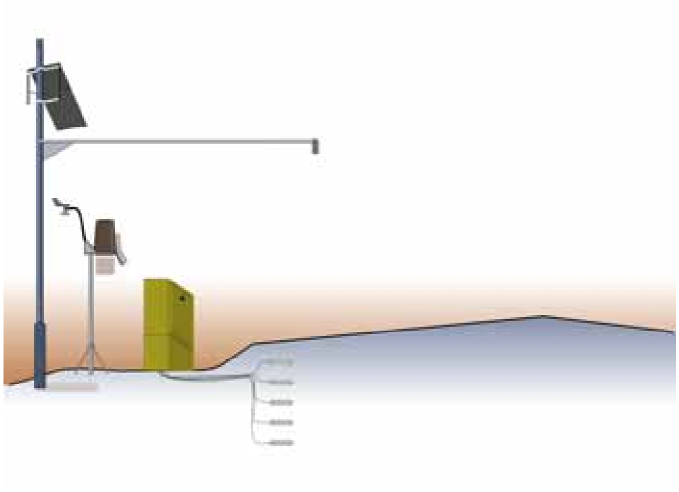

Figure 4. A schematic diagram of an integrated system combining a Percostation and a weather station for use on low volume roads. In addition to the parameters measured by the Percostation (see chapter 6.3), the weather station would measure temperature, wind, rainfall and evaporation and is also outfitted 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.

3.3 Improving winter maintenance practices

In addition to real time monitoring techniques there is one 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.

4 STRUCTURAL CONDITION MONITORING TOOLS

4.1 General

The structural condition of a road is the most critical parameter when considering the asset value of the 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 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).

In most countries and especially so on low volume roads the main problem with regard to structural condition is that when road users or political decision makers finally begin to notice the consequences of deteriorated structures it is often too late or extremely expensive to undertake any rehabilitation actions, because the structures that previously existed have been lost.

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

However, management of structural conditions is not 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.

Another problem relates to the relative short history of the low volume roads in the NP area. Traditionally road regions have focused on constructing new roads and, 10-20 years ago, “strengthening the road structures” was understood, in many regions, to mean the complete removal of the old structures and replacing them with new ones. Unfortunately, this philosophy is in some places still in practice. Perhaps the main obstacles to ending such practices are a lack of training, good models and software for strengthening old roads.

Improving structural conditions can also have positive effects in reducing spring thaw weakening problems and, on the other hand, 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.

The techniques used to monitor structural conditions and parameters for describing them have been another problem. This is discussed in the following chapters.

4.2 Parameters describing the structural condition

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 have 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 E2 value calculated from the FWD measurement data. The problem with this E2 value, originally used with static plate load testing systems, is however that it is so 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). Appendix 1 provides a summary of this work.

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 **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.

4.3 Survey and monitoring techniques

The structural condition of a road has been 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 basically only be used on paved roads and another problem with pavement distress inventory is that problems with the structural condition are identified when it is, in many cases, too late from a sustainable road condition management perspective.

Based on the Roadex II research results the author would suggest that at least two parameters be added to the tools 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 aforementioned 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, the 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. The IRI was 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.

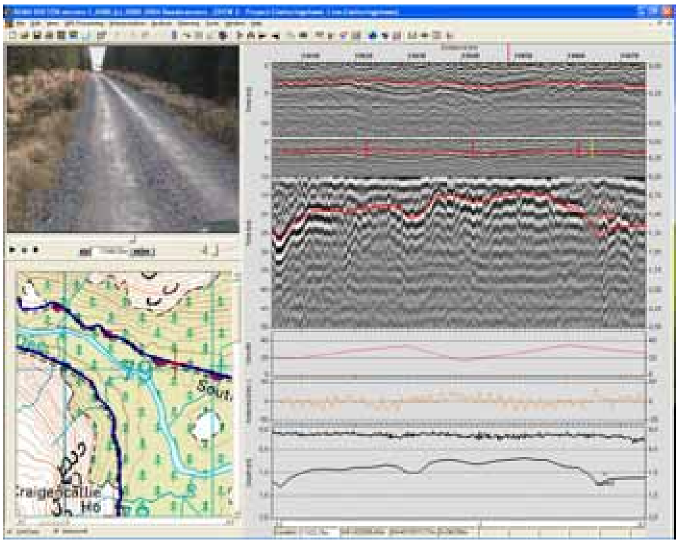

Figure 7. Structural and functional condition evaluation of a forest road in Scotland. The topmost profile presents the GPR data from the 2.1GHz antenna which measures base course and wearing course, if it could be identified. The second field presents combined 2.1 GHz GPR data (top 10 ns) and 400 MHz 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.

4.4 Structural condition assessment – Case B871 Kinbrace - Syre

In 2001, the Forest Enterprise in cooperation with the Highland Council began a project which has been studying the impact of timber transportation on road B871 between Kinbrace and Syre. Reconstruction of the road according to modern standards was deemed too expensive at £ 5 million. Instead a course of survey and analysis was pursued whereby sections that would fail as a result of timber transportation could be identified and further investigated. The project goals are 1) to produce a baseline of the current road condition prior to timber extraction operations, 2) to develop a joint road maintenance management strategy, 3) to permit timber extraction over the public road, 4) to monitor the performance of the public road under timber traffic, 5) to trial innovative road maintenance techniques for keeping the public road serviceable under timber traffic and 6) to share the knowledge and experience gained with other interested bodies.

Integrated analysis was selected as the best method with which to address the task. It is a method that incorporates a variety of modern survey techniques, in this case Ground Penetrating Radar (GPR), Falling Weight Deflectometer FWD), High Speed Road Monitoring Vehicle (HSRM), sampling, Digital Video and the Percostation were used to evaluate and monitor the road. Then an integrated analysis of these survey results was done using Road Doctor software. The FWD results were analysed using Modulus software (Saarenketo and Herronen 2001).

The risk evaluation was done through separate analysis of the condition of 1) surface layers including the performance of pavement and top part of the base (0-200 mm) 2) unbound layers and 3) subgrade. These analyses were based on the FWD data, GPR data and other reference data.

The risk evaluation was based on the analysis of these individual layers and the risk classifications are as follows:

Table 2. Class Evaluation

0. No immediate risk for major pavement failure. Local pavement cracking and an increase in rut depth may occur.
1. Pavement failure and rutting may occur but only after continued timber transportation. Initially these failures will focus on sites where the bound layers are deteriorating or have debonded.
2. Pavement distress (rutting and cracking) will appear on the road a short time after timber transport starts, but they should not cause immediate problems for road users.
3. Severe pavement distress will appear immediately after timber transport commences (less than 5000 axle load cycles). These major damages may cause problems for road users

The risk analysis results predicted that the road will have pavement failures totalling 8.1 km in length immediately after timber transportation starts (see figure 8). Smaller scale failures will occur on a total 11.3 km of road while only 5.5 km of the road is strong enough to support the wheel load of the timber truck without major problems. The worst sections were so weak, partly due to soft subgrade, that if a heavy truck had to stop in these sections, the road could collapse immediately. A detailed description of the high-risk sections were given in the Power Point GIS map presentation included with the report.

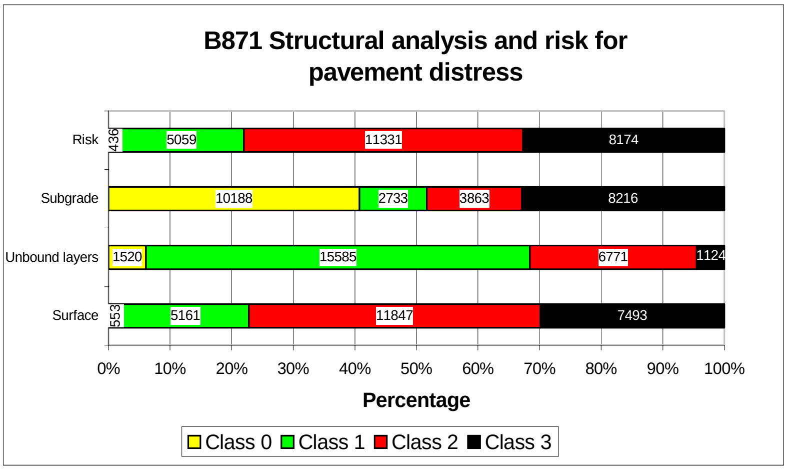

Figure 8. Statistical summary of the risk evaluation of the B871.

Since the timer haulage started the road was videoed yearly. The first video was shot prior to the commencement of timber haulage, to provide a baseline, and then a video was taken every year after (Saarenketo, Aho and Middleton 2005). The development of the following distresses: longitudinal cracking, alligator cracking, ravelling, deformation patching and new pavement were used to identify sections that had failed (figure 9).

Figure 9. A damaged road section at B871.

Following haulage and an overall assessment of the sections that had failed as of 2004 the original risk analysis was revisited and compared with what had really happened. Table 3, which provides an assessment of the accuracy of the 2001 risk analysis, indicates that this structural risk analysis method has worked very well. The failures would have been even greater if the timber haulage had been performed during the period of freeze-thaw cycles (see Saarenketo and Aho 2005). Figure 10 presents the results on a GIS map.

Table 3. Pavement failures 2002-2004 compared with risk prediction in 2001 in B871. Risk classes are presented in table 2.

Risk class	What happened	Percent
Class 3	Failed as predicted	77,6 %
	Starting to fail	13,3 %
	No failures	9,1 %
Class 2	Failures	27,4 %
	No failures	72,6 %
Class 1	Failures	13,2 %
	No failures	86,8 %
Class 0	No failures	100 %

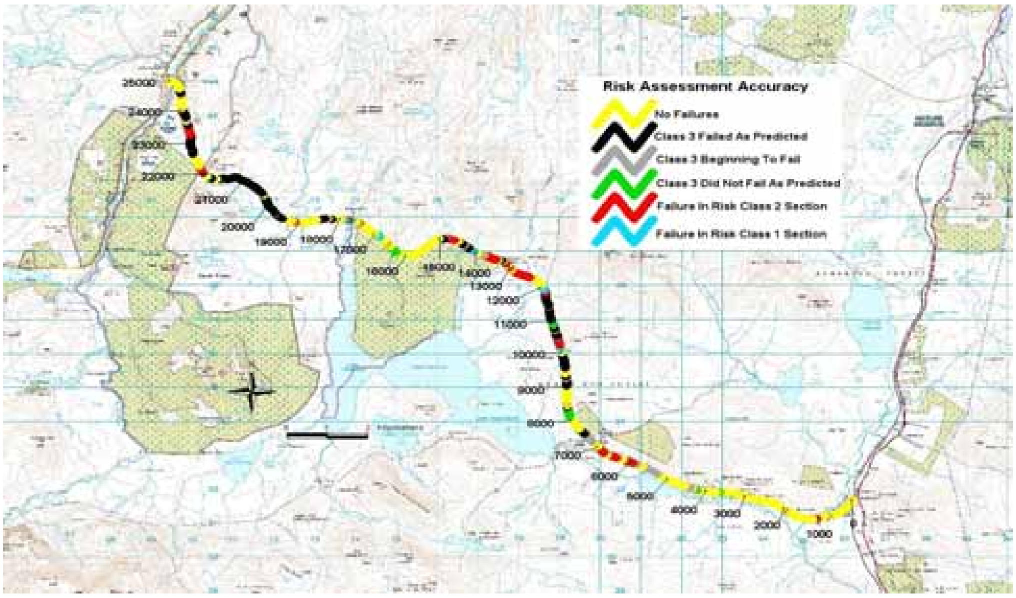

Figure 10. A map showing risk assessment accuracy in road B871.

5 Functional condition and its monitoring tools

5.1 General

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. But functional condition also has a great effect on the transportation costs of the products and thus on the economic life of rural areas. Poor functional condition of the road increases fuel consumption, causes time delays and damages the vehicles using the road.

5.2 Parameters describing the functional condition

The critical parameters that describe the functional condition of low volume paved roads are rutting, surface friction, longitudinal roughness, including bumps and potholes, wide longitudinal cracks. Drive comfort is also reduced by poor patching and deviating cross fall which can cause problems for heavy vehicles especially. 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. However, because rutting has been the main priority for road regions for such a long time without any compromises made when dealing with rut depths, road users generally start to forget that this can be problem. This could also be because rutting problems are generally only visible during rainfall.

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. Even in the Highlands 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 caused by differential frost heave bumps and other 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, conducted by research group under the guidance of Johan Granlund, 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. The problem with IRI values on gravel roads is that they cannot be measured reliably using laser sensors. In Finland the research done by Anssi Lampinen suggests that the best parameter for measuring longitudinal roughness, especially from gravel roads, is the **RMS value** of vertical acceleration.

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 and each country follows different practises when it comes to selecting the lengths used in this calculation. The reason behind the use of these long section lengths is that the basic design of the old PMS systems could not handle shorter sections. When the average values from longer sections were used there were, and still are, many cases where a single and uncomfortable uneven bump located in a section of an otherwise even road will be neglected when decisions concerning rehabilitation measures are being made. Figures 11 and 12 from the Finnish S14 research by (Lämsä and Belt 2004a) describe the problem well. Figure 11 presents IRI results calculated in different lengths of mean values from a typical low volume road with roughness problems. Figure 12 presents the results from the road user panel survey of the same road sections and what mean IRI values should be used to present intolerable bumps. The results clearly show that when 100 m mean IRI values are used it is impossible to detect those sharp bumps that especially heavy vehicle operators consider to be extremely intolerable.

Another consequence of using these long sections on low volume roads is that, generally, the values used to trigger maintenance measures are too high compared to road users' expectations of road conditions. The system however could be improved and the management of low volume road condition become more effective, as a result, if steps towards using shorter sections, in both analysis and rehabilitation measures, were taken.

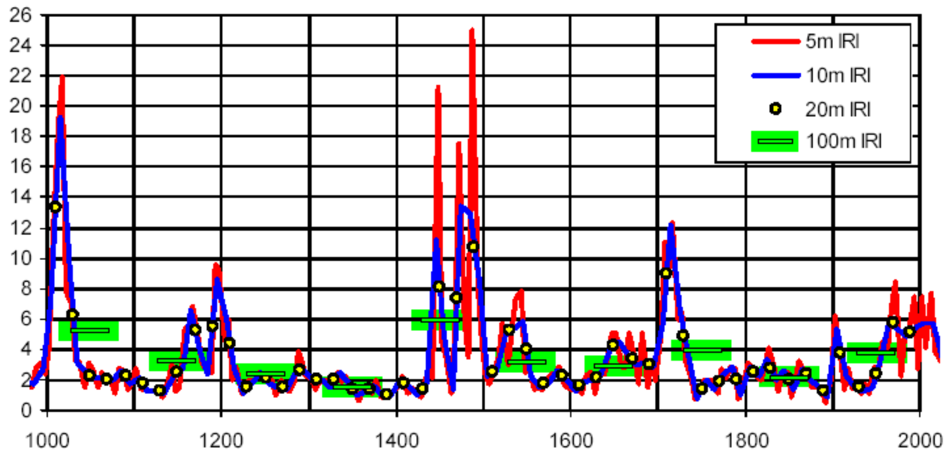

Figure 11. IRI values measured from a poor quality low volume road, Road 8250, section 2 near Oulu and calculated in mean values of 5 m, 10 m, 20 m and 100 m. Figure is modified from Lämsä and Belt 2004a.

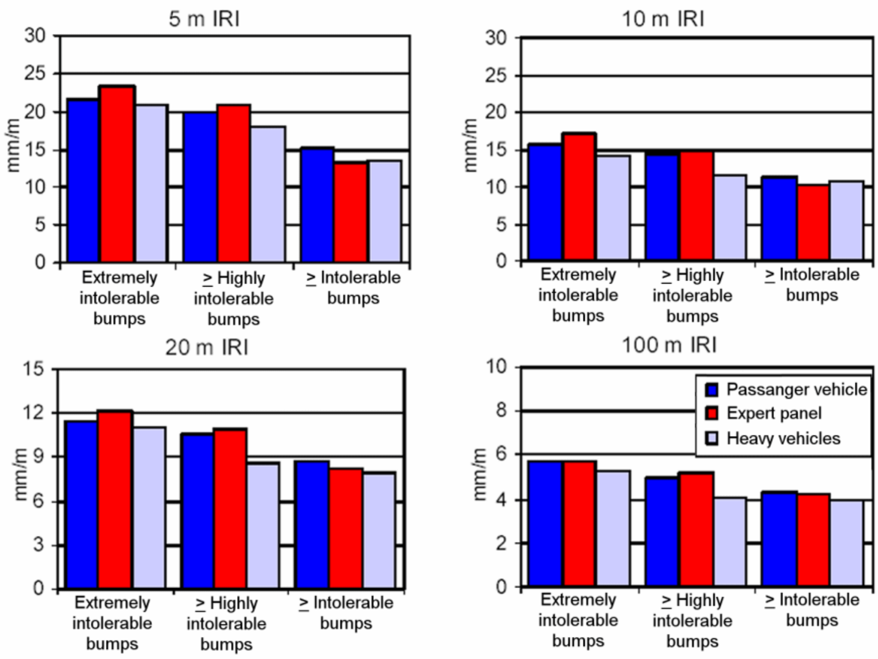

Figure 12. Results from a road user panel survey ranking intolerable bumps on paved roads into three categories: intolerable, highly intolerable and extremely intolerable. Figure is modified from Lämsä and Belt 2004a.

5.3 Survey and monitoring techniques

Roughness and rutting of the paved roads is measured, in most countries, using profilometer techniques that utilise lasers. In addition, these **laser profilometers** can, for instance, measure the cross fall of a road. On low volume roads cheaper systems that utilise **accelerometers,** mounted on the rear axles of a vehicle, to measure roughness and ultrasonic sensors to measure rutting have been used in some countries. Accelerometers are also 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 13). This method allows almost continuous monitoring of the road condition.

However in the near future there will no longer be a need to use relatively expensive laser profilometers to measure surface roughness 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 would also be possible, in the future, to calculate road surface parameters.

Another technique that is currently available is **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. In order to help with classifying problems on gravel road and paved roads several handbooks with photos describing problems and how they should be classified have been published (see figure 14).

Detecting of vibrations from the roads surface

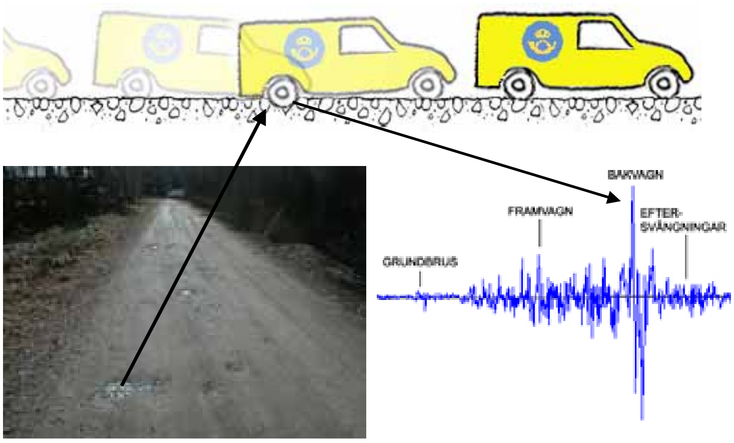

Figure 13. Swedish gravel road monitoring system where accelometer sensors are installed to post vans that are daily using the road network. Figure is from Johansson et al. 2005.

Figure 14. Example of class P1 deep potholes according to the Scottish forest road intervention level description (Forestry Commission 2005).

6 SPRING THAW WEAKENING MONITORING

6.1 General

In the Roadex I and II projects, freeze-thaw cycles and spring thaw weakening has been identified as being one of the most difficult problem areas in low volume road condition management in the NP area. It can be stated that a major part of the damage develops on roads during the spring thaw and if these problems could be handled more effectively the lifetime of the low volume road network in NP areas would be more than two times longer than it is now. Furthermore, 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).

6.2 Critical parameters in monitoring spring thaw weakening

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 of all these categories should be monitored.

Frost depth and **soil temperature** meteorological parameters showing if the materials are frozen or thawed have been the most popular monitoring methods in NP areas. The Roadex II project results (Saarenketo and Aho 2005) have shown that **daily rainfall** is also an important parameter, especially in Scotland, when monitoring risk for road failures after freeze-thaw cycles (Saarenketo and Aho 2005). In the future, one parameter that has the potential to become very useful, especially on gravel roads, is **evaporation**.

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 amount of free water is **dielectric value.** In recent years, trends in discourse amongst road engineers have slowly progressed from discussions of water content to directly discussing dielectric value itself. 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 **recovery times** are also very important parameters to consider when attempting to protect roads from being damaged during the 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. Comparing the data from the stiffer summer months can provide continuous information concerning areas of risk.

6.3 Monitoring and focusing tools

Visual inspection is the most traditional way to monitor spring thaw weakening. However it 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. These plastic tubes, filled with methylene blue liquid that changed colour based on whether or not the material surrounding the tube was frozen, were checked on a weekly basis. Another liquid used in these tubes was polyethylene with green fluorescing dye. However all of these frost tubes broke quite easily and data collection was labour intensive and, that being the case, 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. One thing worth noting with regard to electrical conductivity is that it can also provide very valuable information concerning clay colloids, among other things, during the thawing phase (Saarenketo and Aho 2005).

As stated in chapter 6.2, dielectric value is one of the most critical factors and should be monitored. Dielectric value is an indicator of volumetric free water content and, as such, dielectric value can also be used to determine if the material is frozen. Dielectric value has been 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 will be obtained if a number of parameters are followed 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 15) (Saarenketo and Aho 2005). Monitoring spring thaw weakening through the use of electrical methods is still a new area and, that being the case, the significance of some of the different measurement results are not yet totally understood. But with each passing year more data is gathered, analysed and compared to other data which has led to a greater understanding of the technique and how to interpret the results. Figure 15 presents data from the Kuorevesi Percostation from the spring of 2003.

The stiffness of the road structures and the subgrade soil beneath them during the spring thaw period can be monitored through the use of **Falling Weight Deflectometer** (FWD) and **Dynamic Cone Penetrometer** (DCP). The FWD data especially when collected at different load levels provided valuable data in the Roadex II tests. However, in some weak sections, collection of FWD data was very difficult due to the fact that the road surface was almost plastic. 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 stiffness info, it also provides information concerning the frost depth (Saarenketo and Aho 2005, Aho et al. 2005).

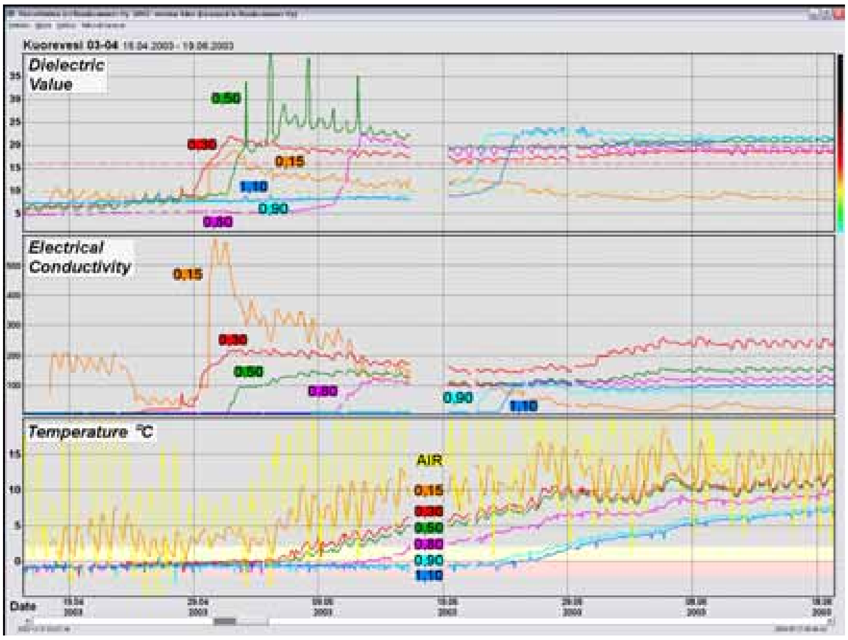

Figure 15. Monitoring results from Kuorevesi Percostation during spring thaw period in 2003.Each colour represent sensor reading from different depths.

The results obtained from the monitoring techniques mentioned above should not just be used to focus the timing of load restrictions and evaluate the maximum allowed axle loads but they can, and should, also be used to diagnose and classify road sections with spring thaw weakening problems. The benefits of these monitoring techniques are that they a) **focus the attention directly on problem sections** and b) facilitate the **selection of the optimal repair technique and structure** for each case. Based on the author's experience and several years of testing different methods the recommended methods for repair design are:

- Spring thaw weakening visual evaluation data is extracted from the data bases
- GPR surveys, a 400 MHz antenna survey is made during the winter when the ground is frozen and the frost line as well as segregation ice can be detected and a 1-2.2 Ghz antenna is used to measure wearing course and base course (if any) during the summer.
- IRI (10 or 5 m mean value) measured during the winter to locate differential frost heave places.
- Digital video which can be used to evaluate the surrounding of the damaged areas as well as drainage
- FWD data from the damaged area which is beneficial when evaluating the stiffness of the road structures and whether the problems are related to peat subgrade or bedrock.

Figure 16 presents an example of the data used to analyse and classify spring thaw weakening sites in Finland.

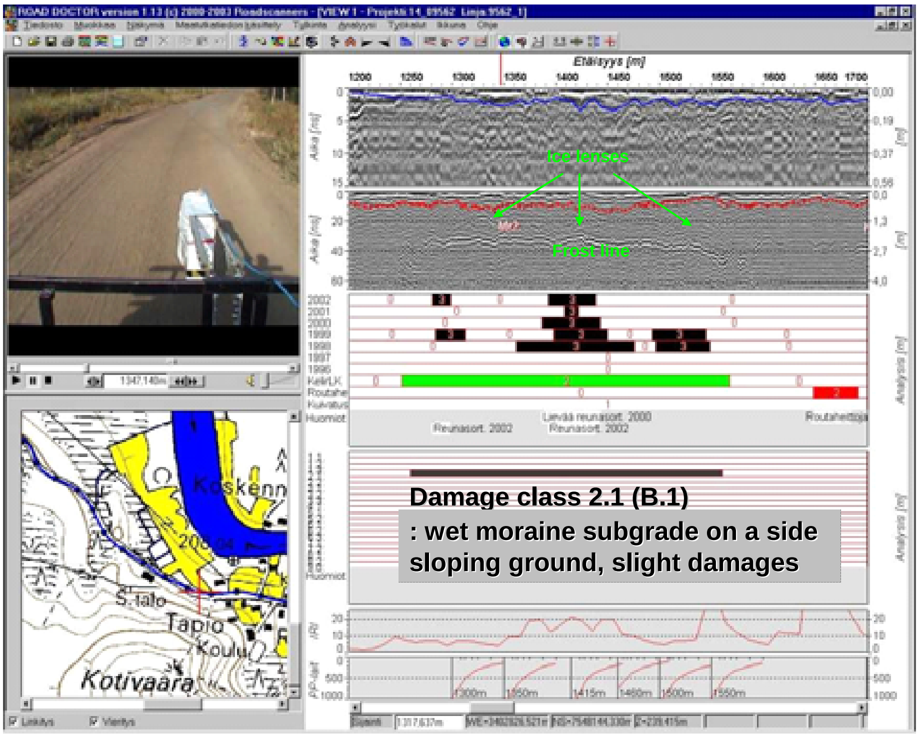

Figure 16. Presentation of the spring thaw weakening classification results with Road Doctor software. The top fields on the right are GPR 1.0 Ghz results showing wearing course thickness and 400 MHz data showing road structures and subgrade down to 4 meters. The third field presents spring thaw monitoring results from 1996 to 2002 and below that is damage classification. Two lowest profiles present IRI values measured during the winter showing uneven frost bumps and FWD deflection bowl data (that could also be presented in the form of SCI, BCI and E2 values).

7 FREIGHT MONITORING

Freight management 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 rural areas of the Northern Periphery.

Conway and Walton (2005) list the following currently available technologies as having the potential to improve truck freight management and operations: 1) weigh in motion (WIM), 2) automatic vehicle identification (AVI), 3) communications and 4) remote and on-board monitoring systems.

There are several techniques that have been tested and that could be used in weigh in motion systems on low volume roads. In the Roadex II partner areas, only Sweden has recently done 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 following technologies: bending beams, piezoelectric sensors and single load cells. In addition to these, new sensors have been developed, of which the types 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 one of the main reasons for that has been 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 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 has especially great potential for managing spring thaw weakening (Saarenketo and Aho 2005).

8 FOCUSING ON THE ROAD USERS NEEDS

8.1 General

The needs of the road users will have an ever increasing role in the road condition management of low volume roads. These needs could be roughly divided into three main categories that are presented below in order of priority.

1. Safety

This category covers all the traffic safety issues 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. Other special safety issues related to winter were risk for avalanches in Norway. But the worst safety scenarios were on roads where poor winter driving conditions occurred in road sections with other specific problems, such as uneven frost bumps, steep hills or tight and narrow curves.

2. Accessibility

After traffic safety, accessibility or regularity is the second greatest priority. In the NP area, low volume roads accessibility problems are mainly related to winter maintenance where snow storms or avalanches block the road. A 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 the procurement policy (figure 17)

3. Specific problems

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 the 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 (see figure 17). 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 considered in the road condition management their ratings of a particular problem were more positive than one would have expected considering the severity of some of the problems according to measured values. A good follow up system is also needed in order to be able to improve the procurement policies as well as the standards used for the maintenance contract bonus systems which are based on the level of road users' satisfaction.

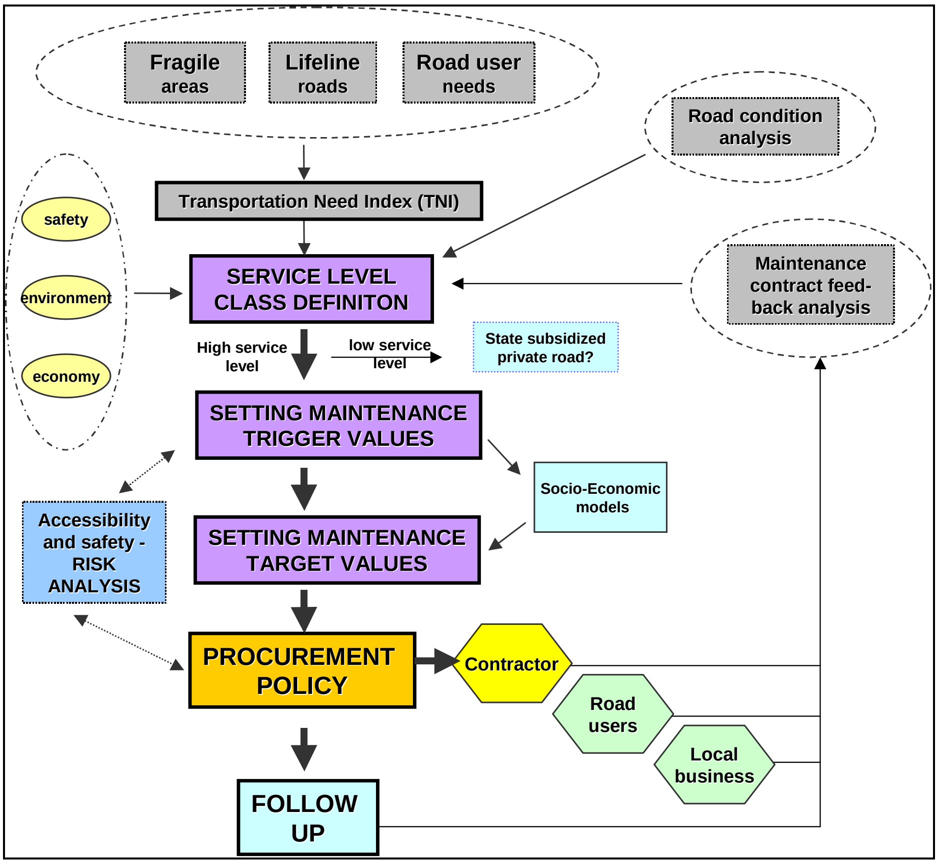

Figure 17. The processes in defining the new road condition management policy for low volume roads for NP areas (Johansson et al. 2005).

8.2 Survey and monitoring techniques

Traditionally road user needs and opinions regarding road condition have been monitored through questionnaires and interviews that have been arranged, more or less, regularly. 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. Project level information has mainly been gathered if the road has been in a design program for heavier rehabilitation measures where landowners are informed about the measures.

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 18 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.

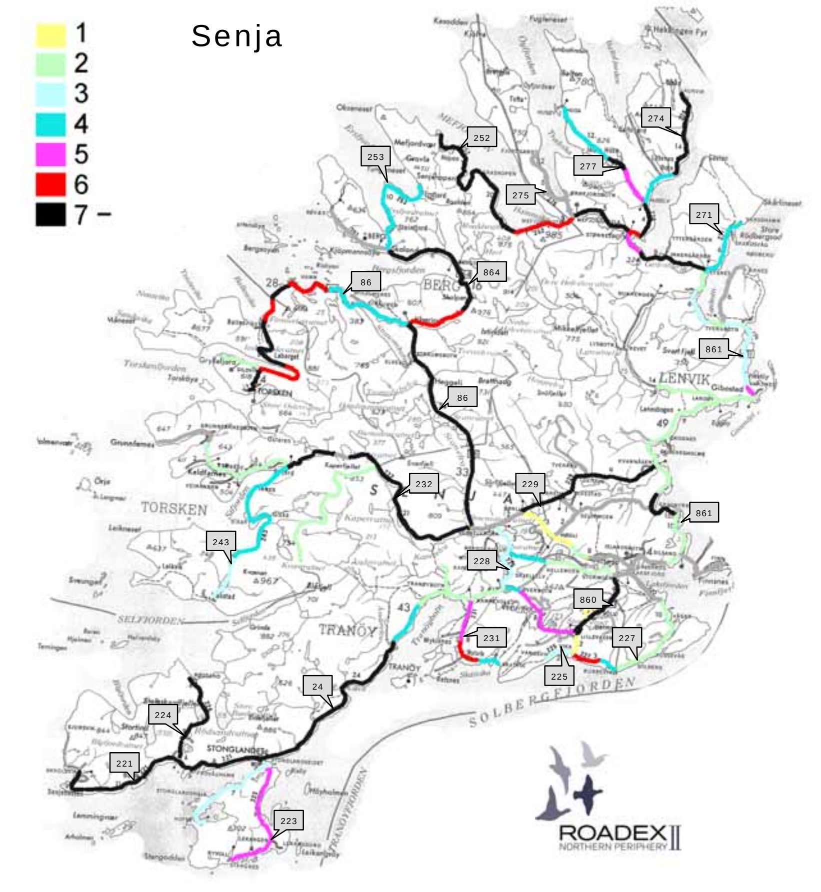

Figure 18. Professional road users opinion on the location of problem roads in summer on the island of Senja in Norway (Saarenketo and Saari 2004).

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).

Road user feedback can be collected directly and road administrations have a telephone number(s) where road users can call and make comments on the road condition. But, in general, these information systems mainly receive information concerning emergency situations and very poor driving conditions during the winter.

One example of a modern monitoring technique for road users feedback and their needs is the "Katukanava" system managed by Finnish Road Enterprise in Finland (figure 19). In this system a road user can provide feedback about the general condition of the road by either sending a text message with a cellular phone or directly marking it on a map found on the web pages. If a cellular phone is used, the information required to mark the problem section on the map is provided by the cellular network provider and is based on the location from which the message was sent. Road users comments are then be stored in a message field on the web page, where road regions and contractors can view them. The place from where the message was sent can be also seen on the map.

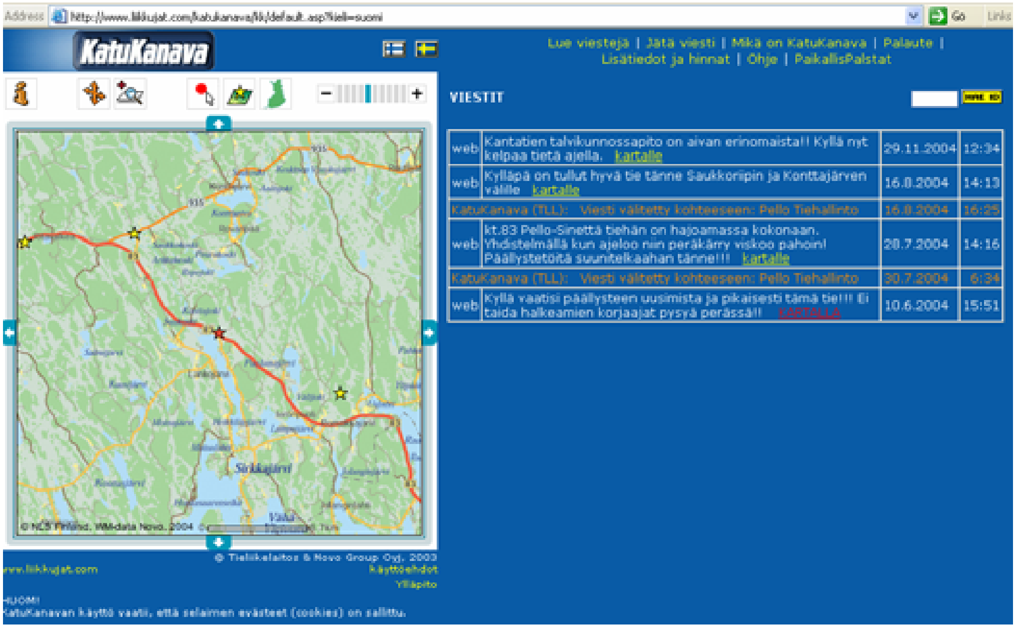

Figure 19. Example of a web display of Finnish Road Enterprise "Katukanava" (Street Channel) road user feedback system. The map shows the places where the comments are coming from and messages are displayed on the right.

9 FOCUSING MEASURES ON THE CORRECT LOCATION

9.1 General

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 with capabilities of handling large amounts of data allow road engineers to define precisely the road sections needing better maintenance or rehabilitation actions and design 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 instance, it does not make sense when GPR can provide data with 1 m accuracy while the design systems only allow 20m sections. Figure 20 provides an example of the processes and data flow in a road strengthening project where all of the processes and data storage systems presented must be capable of handling new types of data with precise coordinates. Some of the key factors and modules needed for better focus are discussed in the following:

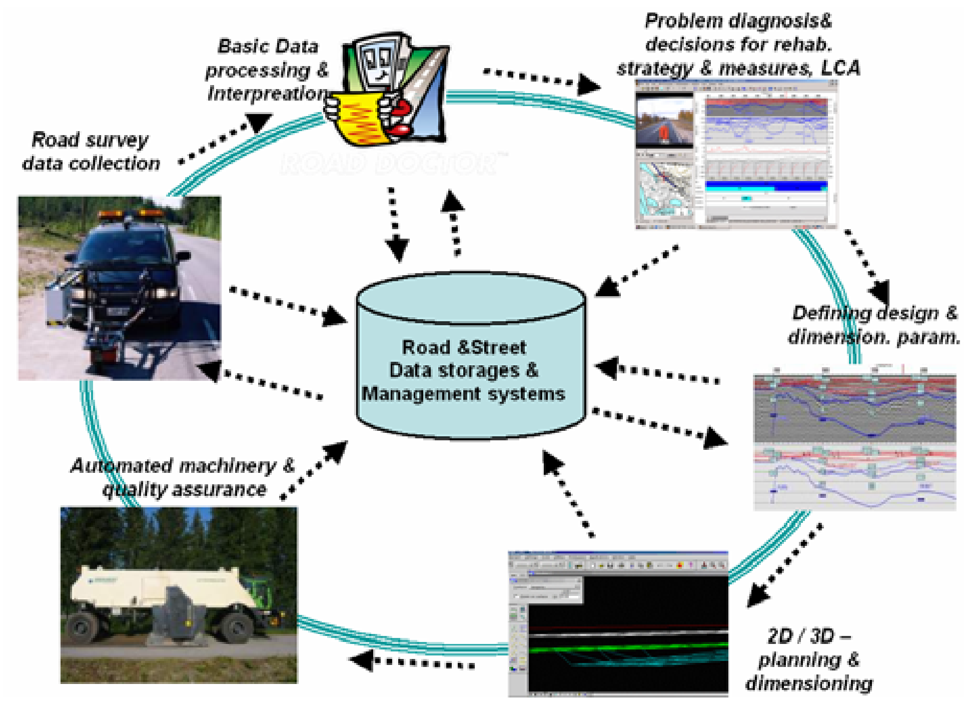

Figure 20. A chart describing modern road strengthening process and data flow.

Road referencing system, Road registers
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 the 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. When road specific information is sent to road users this information will be based on this referencing system.

In Finland this system, called Digiroad, has recently been completed and it covers about 500.000 km of public roads, city streets, rural roads, forest roads and private roads. The original goal for Digiroad, set by the Finnish Government, was to promote development of navigation, route planning and traffic guidance services for travellers and road users (see figure 21) but it also offers numerous possibilities for improving road condition management on low volume roads. More information of the Digiroad can be downloaded from http://www.digiroad.fi/Esittelymateriaali/en_GB/publication/.

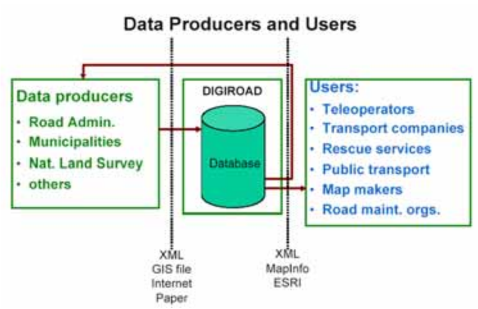

Figure 21. Digiroad data producers and users.

Road survey and monitoring systems
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.

Data storage
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 are designed to handle the data on a national level are not suitable. The new module based data base systems 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 do 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 the 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

Positioning and referencing systems
An extremely important thing when moving towards more focused road measures is to have common positioning and referencing systems that everyone participating in the process understands and can easily check. A good example further emphasising this issue comes from Finland where one of the biggest causes of failures on spring thaw damage site rehabilitation sites was that contractors had built the structures in the wrong place as a result of a poorly working positioning and referencing system.

9.2 New positioning tools facilitating better focus

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

- Positioning systems based on the measuring distance from a known reference point (DMI, trip meters)
- Positioning systems that are based on Tachymeters (optical systems)
- Positioning systems based on linking the data with digital photos or videos from the surveys site
- Wireless electronic positioning systems

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. The following summary of electronic positioning is mainly based on the paper by Antti Rainio (2003).

The wireless electronic positioning systems are mainly based on the calculation of distances by measuring signal travel times. These systems can be classified into three main areas:

- network positioning
- local area network positioning
- satellite positioning

Network positioning is based on cellular phone positioning techniques. Local Area Network (LAN) positioning is based on the use local wireless networks and other short distance radio networks that can be used in city centres and offices. Figure 22, provides an overview of different positioning systems which clearly demonstrates that the only system that could be used in rural areas are based on the different kinds Global Positioning Systems (GPS).

GPS has been developed in USA and it has become much more accurate since spring 2000 when the US government stopped the use of selected availability (SA) for non military applications. Other satellite positioning systems are the European Galileo system and Russian Glonass system. Satellite positioning systems include the following specific systems:

- GPS (Global positioning system)
- Differential GPS (DGPS)
- Real Time Kinematic GPS (RTK GPS)
- GPS pseudolite systems
- Assisted Global Positioning Systems (AGPS)

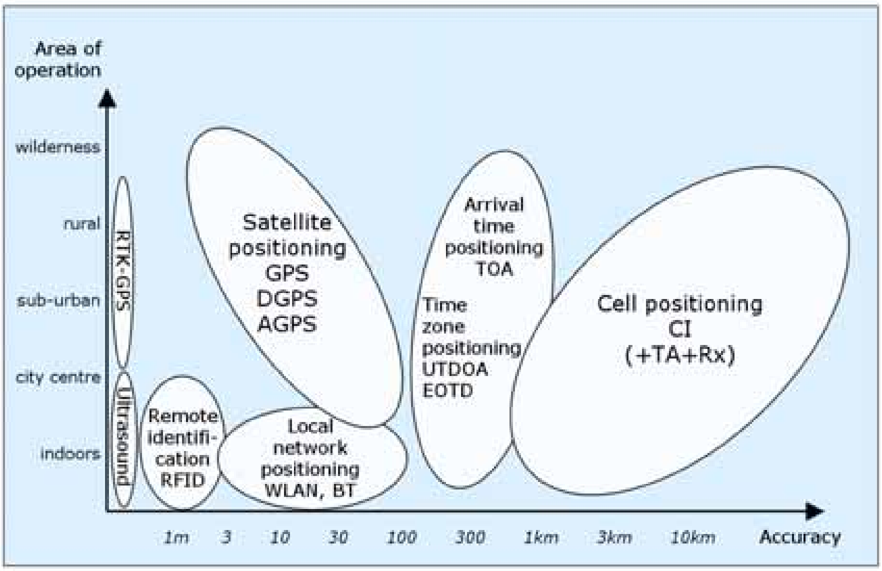

Figure 22. Different wireless positioning systems and their accuracy (modified from Rainio 2003).

Normally the accuracy of standard GPS systems is roughly 10 m but in city areas or in dense forest areas it decreases often to even less than 20 m.

The most accurate system is RTK GPS but because these measurements require that one reference unit must be installed on a known point within a few kilometres and because one measurement requires static readings for up to one minute this system is too still complex and expensive for most low volume road applications.

In the future the most popular positioning systems will most likely be so called hybrid systems where several positioning systems and techniques will be used simultaneously, which will improve data quality. The quality of positioning data can be improved through the use of different kinds of sensors that measure the direction of the movement, such as a magnetic compass or a fibre optic gyroscope. Also the use of maps and map matching techniques will help in improving the positioning quality.

One probable option for future data collection, positioning and wireless communication system is the use of new "smartphones" or navigation phones that are basically small handheld computers that have built-in positioning systems or that can read positioning info from a GPS unit. Another possibility is that the use of car navigation systems will spread. Fleet management or freight management systems that are used in trucks can be classified into the same category. All kinds of new sensors can be linked to the "black boxes" installed in trucks facilitating both the collection and transmission of road condition or truck weight data.

Rainio (2003) has predicted three waves in the evolution of the positioning industry (figure 23). During the first wave, vehicle navigation systems will enter the market. After that, the second wave will bring applications for mobile work that requires positioning systems as well as personal navigation services. With the third wave, cargo and product packages will have remote identification systems and the technology to provide close distance guidance will become available. For road condition management in rural areas especially the first two waves will offer huge possibilities of improving the precision and timing of measurements, services and measures.

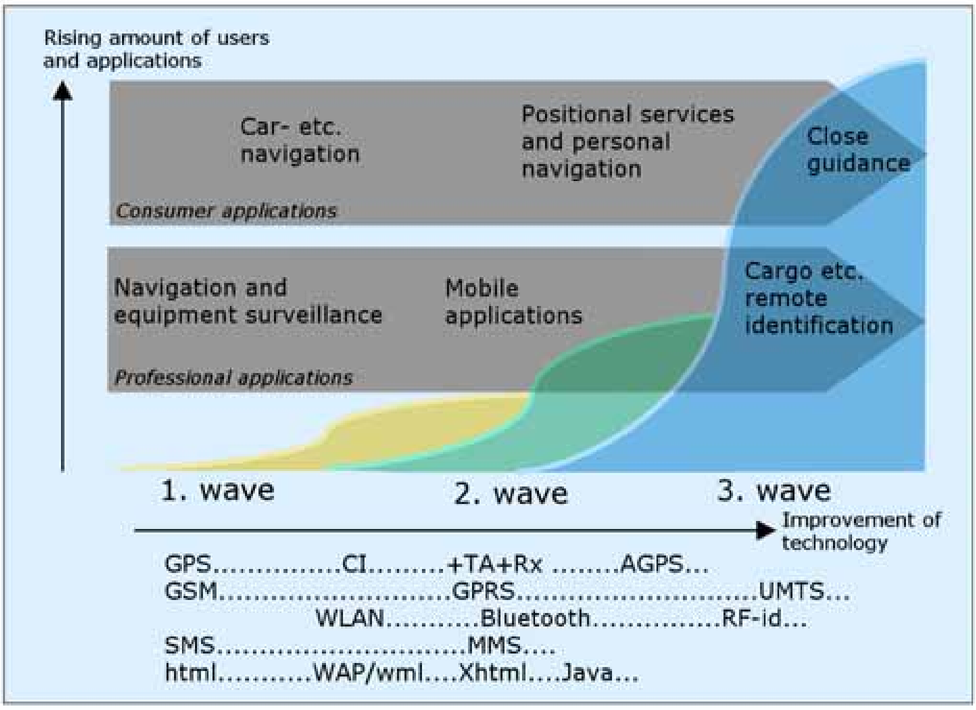

Figure 23. Evaluation of the trends in the positioning market (modified after Raunio 2003)

9.3 Ideas / Examples to improve focus in low volume road management

There are numerous opportunities to improve road condition and save money by using better focused systems on low volume roads. Two examples that are related to low volume road condition problems already reported earlier in the Roadex project are given in the following:

Focusing to improve the management of drainage system

Roadex II report by Berntsen and Saarenketo (2005) has clearly shown that in the areas with poorly working drainage the lifetime of the paved roads can be increased by a factor of 1.5 to 2.5 if drainage is improved and well maintained. Previously the Roadex I project had shown that poor drainage is one of the biggest problems shared by all of the Roadex partners. Because poor drainage causes problems only on certain road sections there is a clear need to establish a system to focus drainage improvements only on the critical spots. This could be done in the following way:

a. In the first step both lanes of the road are surveyed with profilometers (if data is not already available) and a digital video of the drainage on both sides of the road is collected
b. Based on the video, the road is classified into three classes (see Berntsen and Saarenketo 2005)
    1. road is located on an embankment
    2. road is located in a road cut
    3. road is located on sloping ground with one side of the road in a road cut and the other side on an embankment
c. The drainage condition of both sides of the road is analysed and classified using digital videos or a series of still photos

d. Data a, b and c are integrated and then analysed in order to locate the road sections where rutting (and pavement damage) can be related to poorly performing drainage. The normal rutting values, presenting a working drainage system, are calculated from the class 1 sections where the road is built on an embankment. If the rutting level is higher in classes 2 and 3 the most likely cause is poor drainage.
e. Based on the results of analysis d, drainage improvements and a monitoring plan are made for these sections. In the maintenance contracts these sections could also be put into a special maintenance class.

Focusing the use of dust binding chlorides

As stated earlier in this report, dusting on gravel roads reduces drive comfort and traffic safety for the road users and it also causes problems for people living close to the road. Dusting can be prevented by increasing the suction properties of gravel road wearing course and this can be made by increasing fines content (matric suction) or by adding chlorides to the material (osmotic suction). However, as reported in the Roadex II spring thaw weakening management policies report (Saarenketo and Aho 2005), increasing fines content, making too thick a wearing course or adding too much dust binding chlorides can cause problems on the road especially during the surface thaw weakening period in spring and also during periods of heavy rain in fall.

Because dusting is only a problem on road sections that are located on a dry subgrade or that have road structures thick enough to cut capillary connections and because road sections in wet areas do not need chlorides there are no benefits to spreading chlorides over the entire road. GPR tests done on gravel roads have also shown that, due to osmotic forces, chlorides in moist areas spread to the ground water very quickly.

The problem however is that there has been no way to locate these "dry" areas that are in need of dust binding chlorides and at the same time maintenance trucks have not had systems that could control where chlorides were spread. The solution to these problems may be found in the application of GPR techniques. Several tests utilising GPR horn antenna surface reflection techniques (See Saarenketo and Vesa 2000) have shown that dry areas needing dust binders can be identified based on the dielectric values of the road surface. The distribution plan for these chlorides could be done in the following way:

a. dielectric value of the gravel road surface and wearing course thickness is evaluated using high frequency GPR air coupled antennas and the surface reflection technique.
b. based on these surveys the road is divided to sections with "high", "low" or "no" need for dust binders and a data file is prepared
c. this data file is downloaded to a computer located in a maintenance truck – or the truck can download them through a GPRS connection or portable memory device
d. while spreading the dust binding chlorides during the spring the truck computer automatically controls the amount of chlorides spread onto road or it gives instructions to the truck drivers as to where and how much salt should be used.

Figure 24 provides an example of using this technique on road 19693 near Rovaniemi, Finland. In this typical case almost half of the road did not need binders at all and increased amount of chlorides would have been beneficial only on a 2500 m long road section.

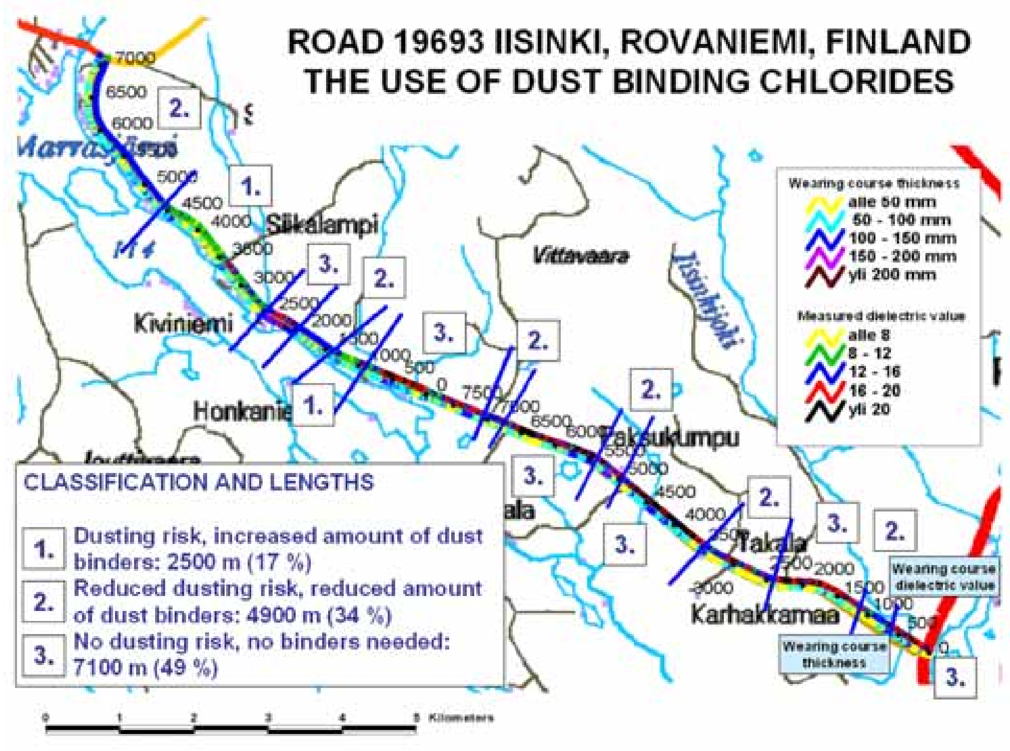

Figure 24. A map analysis showing the need of dust binders on gravel road on road 19693 on Rovaniemi. The same map also shows road sections that need new wearing course material.

10 DESIGNING MONITORING SYSTEMS

10.1 General

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 d) 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:

- Sensor type and amount
- Location of sensor installation
- Data collection density
- Positioning (especially when using moving vehicles)
- Data transfer
- Data storage and processing
- Implementation of the data and decision making system
- Information system

10.2 Sensor type and their installation

Once the problem has been defined the next step is to decide what type of sensors should be used and where they should be installed. For instance, if the goal is to measure roughness then one can chose from laser sensors, which can be used to measure surface texture and IRI values from paved roads, or acceleration sensors, which are less expensive and not as accurate but can also be used on unpaved roads. 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 type of sensors is also 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. A good example is monitoring the weights of heavy vehicles. This can be done through either weigh stations or portable weigh scales both of which are expensive systems and difficult to utilise on low volume roads. But, as described in the Roadex Spring Thaw Management report (Saarenketo and Aho 2005), in the future, vehicle weights could be monitoring through ASSWS (Air Spring Suspension Weigh Sensors) installed on heavy vehicles.

10.3 Data collection density

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.

10.4 Positioning

As stated in earlier, 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 GPS data, DMI data (Distance Measurement Instrument, trip-meter) and digital video frame links. In such cases, monitoring data can be positioned correctly even though one system has failed. Figure 25 presents an example of a GPR system equipped with three positioning systems.

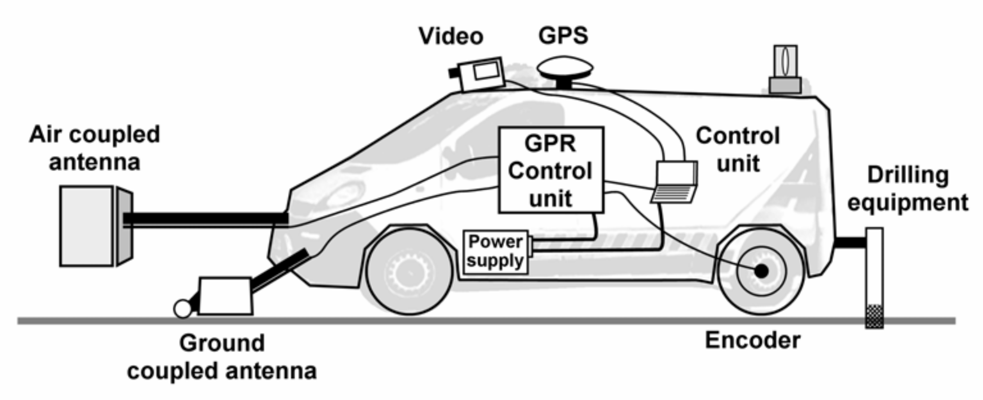

Figure 25. A GPR system used for road surveys in Finland. The positioning is ensured by using GPS, digital video and an optical encoder defining a fixed interval for distances between each scan. A special control unit prepares a log file from the data collection that can be used to link these measurements together.

10.5 Data transfer

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 modem connection. In Percostations, used to monitor spring thaw, data is stored temporarily in the station’s internal memory and then it is downloaded 3-4 times per week and every day during the most critical periods. Wireless data transfer techniques have frequently demonstrated superior performance over landlines since they are less susceptible to damage caused by electrical storms or high winds.

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.

10.6 Data storage and processing

Often, valuable data collected in the field cannot be used to its full potential because the data storage has not been properly organized. This is especially the case when collecting functional or structural data. The national pavement management systems in each NP country have a proper system for storing the data, but as has been stated numerous times in this paper, this data is, frequently, not suitable for use in highly focused low volume road measures. Currently, data storage is a major problem especially when systems that create very large data files, such as GPR or digital videos are stored. However, the prices of hard drives have gone down and hard drive data capacity has increased at such a rate that this will not be a major issue in the future.

A bigger issue is that the collected data is processed and its' quality checked with special attention given to ensuring that the positioning information is correct and properly linked to the corresponding road section in the road data storage system. This requires specialized personnel and, as such, data storage and management would seem most likely to be a system that will be handled by service providers.

10.7 Implementation and decision making process

When designing future monitoring systems, a very important issue for consideration is how the monitoring results are applied and how the decision making systems, based on the collected information, should be arranged so as not to obstruct the process. Based on the author's personal experience and observations, 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.

10.8 Information system

In most monitoring systems 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 26 present an example of such a system already in use in Finland for monitoring maintenance measures. Figure 27 presents and idea suggested by Saarenketo and Aho (2005) for a spring thaw weakening management system for low volume roads in the NP area.

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.

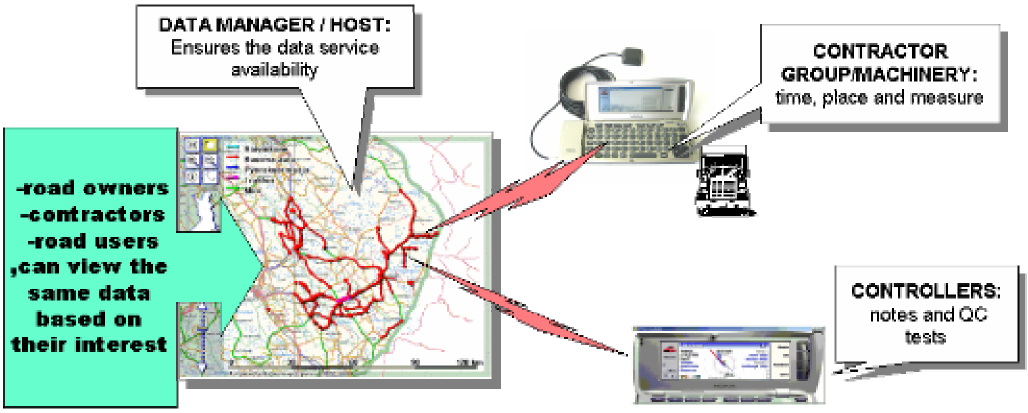

Figure 26. A description of information systems used in Finnra maintenance contracts in Finland. System consist of web based GIS data base system that is hosted by data manager service provider. Contractors inform all the maintenance measures trough wireless links to data manager where road owner can 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 after Tervo 2005.

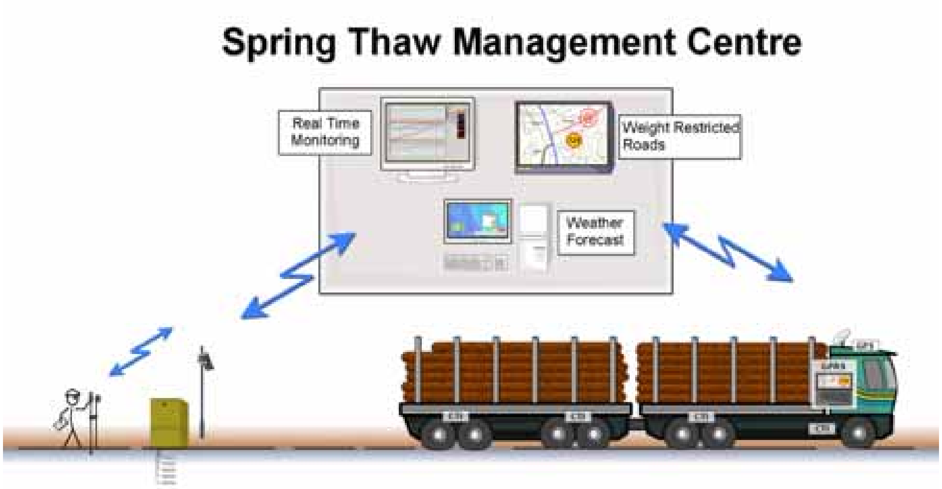

Figure 27. Schematic description of technique for managing spring thaw weakening (Saarenketo and Aho 2005) (see also chapter 11.2)

11 MOVING TOWARDS INTERACTIVE LOW VOLUME ROAD CONDITION MANAGEMENT

11.1 General

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, opens 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 a task 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 28 describes the future playing field of monitoring and managing low volume roads in NP areas.

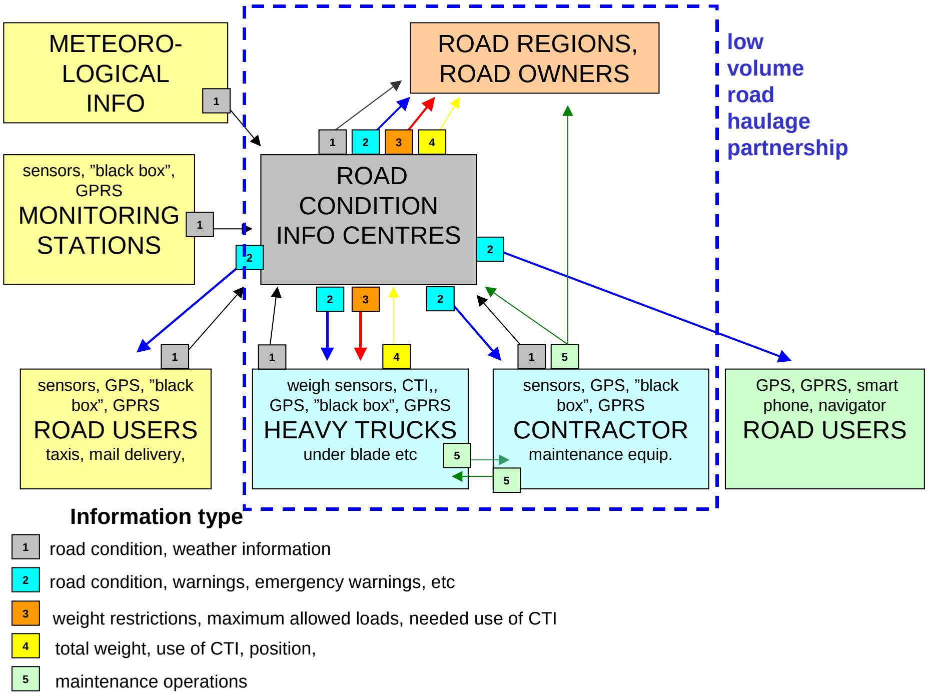

Figure 28. Future playing field of monitoring and managing road condition on low volume roads in the NP area.

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. A good case of such a work and presenting possible future is the Saskatchewan Rural Partnership Haul Program that will be discussed in the following:

11.2 Case: Saskatchewan Rural Partnership Haul Program

In an initiative to facilitate efficient commercial transportation in remote northern and rural areas, a project was undertaken by Saskatchewan Department of Highways and Transportation (SDHT) in partnership with private commercial carriers with the primary goal of allowing larger truck configurations to haul primary weight limits on selected secondary highways if the vehicle utilized road friendly vehicle technologies, such as air-spring suspensions and central tire inflation systems. Under the terms of the multi year partnership agreement, the carrier and the SDHT share the savings generated using more efficient vehicle configurations. This has meant that the carrier pays an incremental cost for bridge and pavement use plus half of the net difference in trucking cost to SDHT´s transportation Partnership Fund (Conway and Walton 2005). In practice this meant that the limit for a standard six axle went from 40.000 kg to 46.500 kg, which led to cost savings of 20%. The limit for nine axle B-trains went from 54.500 kg to 70.500kg, 77.500kg and even 94.500kg, depending on the situation, which led to savings as high as 50 percent in some cases. As of 2001, participation was voluntary and had generated savings of 7 million dollars per year. The haul savings are used by the SDHT to pay for road improvements, once the administration costs have been covered, and are profit for the carrier once the startup costs have been recovered.

The system has thus far been based on manual submitted reports by the carriers which were in turn manually audited by the administration. This system could only be undertaken by large carriers. If the system were to be extended to smaller carriers a system which could automatically allocate saving and do compliance auditing would avoid many of the errors and reduce the labor involved in auditing and administering such a project.

In order to make this system more efficient International Road Dynamics Inc. (IRD) proposed to develop and implement an automated vehicle monitoring and audit system designed to facilitate the Saskatchewan partnership program The automated vehicle monitoring and audit system that they designed employs four primary systems: onboard vehicle data collection/storage system, communication network, central administration system, and remote user query systems.

The onboard system can determine the approximate weight (± five percent) of the vehicle according to the pressure in the air-spring suspension system. The onboard system can be programmed to automatically monitor pressure readings whenever the vehicle stops for more than one minute. The CTI sensors are used to monitor inflation pressures of all the tires and are required on all secondary highways to reduce road damage. All onboard sensor information is automatically stored and cross referenced with position(GPS) by the onboard data storage unit to determine if tire pressures and/or weights are correctly set in relation to the allowable axle weights corresponding to the type of road on which the vehicle is operating (i.e. secondary or primary) and the seasonal environmental conditions.

The primary function of the central administration system is to create and maintain a truck fleet database, perform compliance audits and provide details of vehicle trips including haul savings, and to perform user defined queries. Because many public road authorities employ a geographic information system (GIS), the central administration system is designed to interface with industry standard GIS systems to provide highway names and section locations referenced by GPS coordinates. The data stored by the onboard units can be programmed to download to the central administration system several times per day. Vehicle data transmission is over circuit switched cellular network (figure 29).

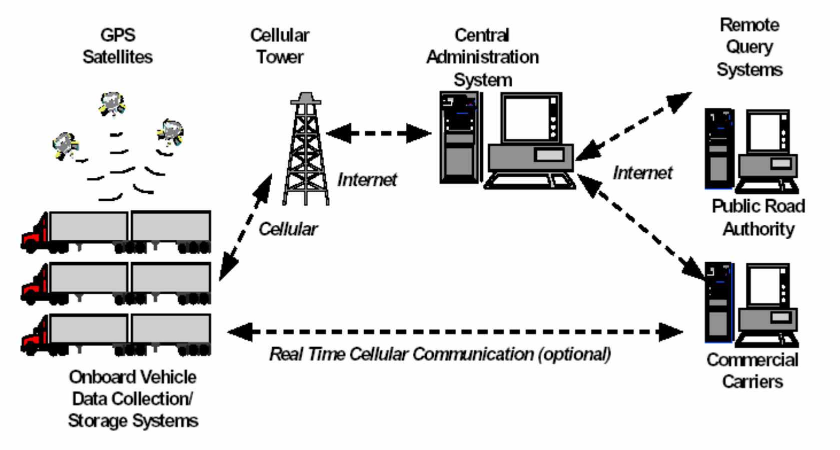

Figure 29. Description of Saskatchewan rural partnership haul program system data flow.

Remote query systems provide the ability for commercial carriers and public road agencies to generate reports including vehicle routing, non-compliance, and audit reports. Routing reports are provided for billing and revenue allocation purposes and may include a summary of trips with a daily breakdown with respect to primary, secondary and municipal roads by route number, section number, and public road authority. Road usage reports can be provided across commercial carriers and road authorities by truck and/or road section.

The advantages of the automated vehicle monitoring and audit system over other commercial systems is its reduced communication costs and the system's inherent flexibility to be readily customized for small to mid-size fleets for diverse fleet management applications. These applications include: near real time vehicle tracking, dispatch and communication, traffic generation/destination studies, road preservation operations management, traffic data collection, onboard system monitoring, fleet logistics administration, and cargo tracking

The report does not provide any results concerning implementation of the automated system. The savings discussed in the first part of the report are based on the manual reporting method.

12 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 the maintenance and rehabilitation measures on an exact spot, improve the timing of measures and also select an optimum measure for each location.

First the key areas of low volume road condition management that require different monitoring techniques are presented in the report. It also presents critical parameters that should be monitored in each area and techniques used to measure them as well as the consequences for road owners and road users if they are neglected.

This report also describes parameters and the current and future tools for monitoring winter condition, structural condition of the road, functional condition of the road and monitoring spring thaw weakening. New techniques for freight management are also discussed. A short description is also given of how road user needs and their opinions concerning road condition could be monitored. This is one of the key issues in the Roadex II proposal for new low volume road management policies in the NP area.

Correct positioning is the most critical issue when moving towards better focused measures on low volume roads and this report describes both positioning and data transfer techniques that are available or that will become available in the near future. A description of the factors and problems that need to be solved when designing a monitoring system is also given in the report.

Finally, some ideas for developing interactive low volume road condition management systems are given in the report. The only way to improve the effectiveness of management systems for low volume roads it to establish new types of partnerships where vehicles of the local road users, who routinely make use of the road network, will be equipped with new sensors that monitor road condition and transmit real time information about any problems if needed. Another new partnership that should also be considered is one between road haulage companies, road owners and maintenance contractors geared towards managing problems caused by spring thaw weakening.

This report also presents new ideas and innovations that could be used to solve or minimize some problems that have been identified in the Roadex project.

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Appendix 1 – Network Level Bearing Capacity Surveys on Low Volume Roads in Region Mitt in Sweden

INTRODUCTION

In 1998-2002, Region Mitt of the Swedish National Road Administration (SNRA) conducted a network bearing capacity – road condition survey to be used for planning and maintenance and rehabilitation design purposes. This project covered about 5 000 km of mostly low volume roads. The main purpose was to collect information regarding the structural condition of the road network and to localize sections with insufficient bearing capacity. But also information about functional condition was collected and analysed. A secondary aim was to combine all of the road data for use in designing rehabilitation measures for sections with low bearing capacity.

SURVEY METHODS

In the survey modern non-destructive measurement methods were preferential. The survey methods included:

- Digital video capture
- Measurement of the structure with ground penetrating radar (GPR) (see figure 1).
- Measurement of the bearing capacity using falling weight deflectometer (FWD)
- Sampling and laboratory testing
- Visual inspection of the drainage
- Visual inspection of the road surface condition and damages
- Rutting and roughness measurements using laser profilometer.

The GPR measurements were done with two different antennas; one 400 MHz ground coupled antenna to examine the lower layers in the road structure and assess the subgrade soil type; and one 1 GHz air coupled antenna to survey the pavement and the base course (see figure 1). The sampling density was 10 scans per meter. A video camera was fixed on the roof of the survey car to make a video of the road, which could be used to identify surface damages and drainage problems. The operator also provided commentary on the video, during collection of the GPR data, noting surface defects and drainage problems. The data was positioned using GPS, the optical encoder of the GPR system and a DMI (distance measurement instrument). The measurement speed was approximately 30 km/h.

The bearing capacity was measured with falling weight deflectometer (FWD). Paved roads were measured with 10 measurement points per km and gravel roads were measured with 20 measurement points per km spaced equally on both sides of the road. The measurements were performed according to SNRA's method description VVMB 112.

Figure 1. GPR survey car mounted with 1.0 GHz and 400 MHz antennas.

Samples from the road structure were taken at a frequency of one sample per km in order to verify the GPR interpretation results of structure thickness and partly to examine the technical properties of the material. Grain size distribution analyses of the material in the unbound road base, the sub-base and the subgrade were performed. Decisions regarding the location of the sampling points were based on the GPR results.

The purpose of the visual inspection survey was to locate and classify pavement distresses and classify the quality of the drainage system as well as to locate culverts in the road structures. The GPR data, video and video commentary from the surveys were used to complete the visual inspections.

In the survey, road profilometer data from the databases owned by the Swedish Road Administration was used to analyse the history of roughness and rutting. The norm in Sweden is to measure IRI and rutting as an average of 20 m and 400 m.

INTERPRETATION, INTEGRATION AND VIEWING OF SURVEY DATA

The GPR interpretation and the integration of all the measurement data were done with Road Doctor™ software. All data were positioned and stored in a menu tree from which the user can select data to be viewed on the computer screen. Figure 2 shows an example of a view from a paved road.

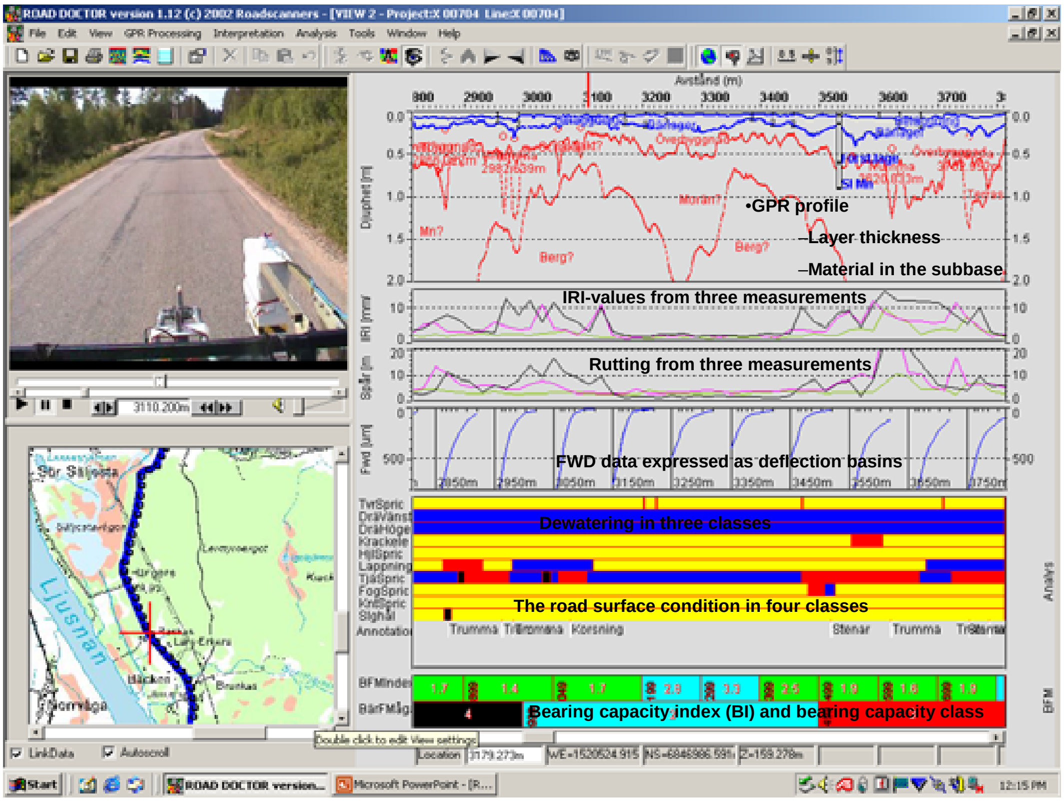

Figure 2. View in Road Doctor from a paved road with different road data.

ANALYSES OF MEASUREMENT DATA, PAVED ROADS

Bearing capacity

The Bearing capacity Index (BI) is a parameter calculated according to the following formula from SNRA's method description VVMB 114:

$$BI = \frac{1000}{\varepsilon_a},$$

where ε_a is the asphalt strain calculated from the temperature corrected FWD results. The lower the BI the worse the bearing capacity is. The BI is shown in the upper of the two lowest bars in the figure 2. The lower bar presents the mean Bearing Capacity class value (BC) of 500 m long sections of the road. The BC value is calculated according to a specification described in method description VVMB 114 where the BI is related to the accumulated standard axles passing the road during the dimensioning period. The Bearing Capacity, shown in the bottom graph, is divided into 4 classes where Bearing Capacity class 4 is a very badly damaged road.

REMAINING LIFE TIME

To predict the remaining lifetime of a road length, calculations have been done by using the measurement results of rutting and roughness measured as IRI. The calculations have been performed using average values of 500 m road lengths. A regression line for rutting and IRI is drawn by means of at least three measurements coming from different years on each road project. Then the critical limit for the 500 m average value of rutting is from experience determined to 12 mm and the life length can be calculated. When the regression line hits the limit value in the time schedule it is the predicted time for a rehabilitation need (see figure 3).

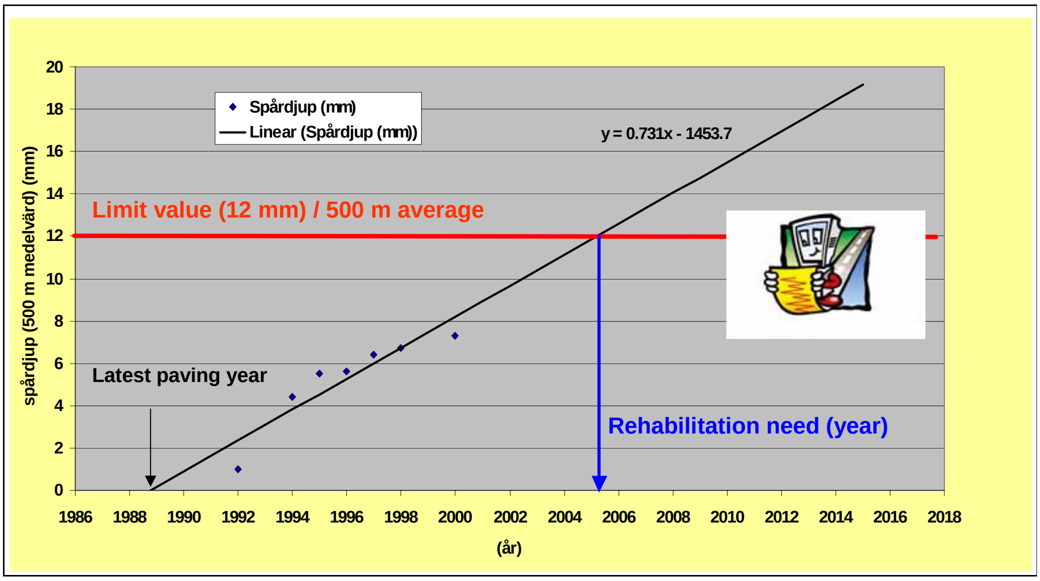

Figure 3. Principle for calculation of life length from rutting.

The same procedure is used to calculate the life length based on roughness expressed as IRI. Then the limit for the IRI-value is determined to 5 mm/m as an average of 500 m when a rehabilitation measure is needed.

PRESENTATION OF SURVEY RESULTS

The results from every project are presented on paper in longitudinal profiles. All the data are linked together so it is possible to take a virtual trip on the road and see how the road conditions are changing throughout the ride. Combining all of the road condition data makes it possible to make a thorough investigation and then an accurate diagnosis of the causes of a road's problems which, in turn, facilitates the selection of optimal rehabilitation measures and their implementation in the right place.

The bearing capacity results and the results from the life length measurements are shown on GIS maps (see figure 5) in an interactive Power Point presentation. For every paved road the following results are shown:

- Bearing capacity class 1-4 including distribution in percent for every class in the project. Figure 6 present statistical comparison of bearing capacity classes of the roads surveyed in Gävleborg County in 2002.
- Bearing capacity class, statistics for the county and survey year
- Lifetime depending on development of roughness expressed as IRI
- Lifetime depending on development of rutting (figure 7).
- Distribution of IRI and rutting
- Photos of bad spots

Figure 4. Example of a GIS map presenting bearing capacity results on road 613 in Gavleborg county.

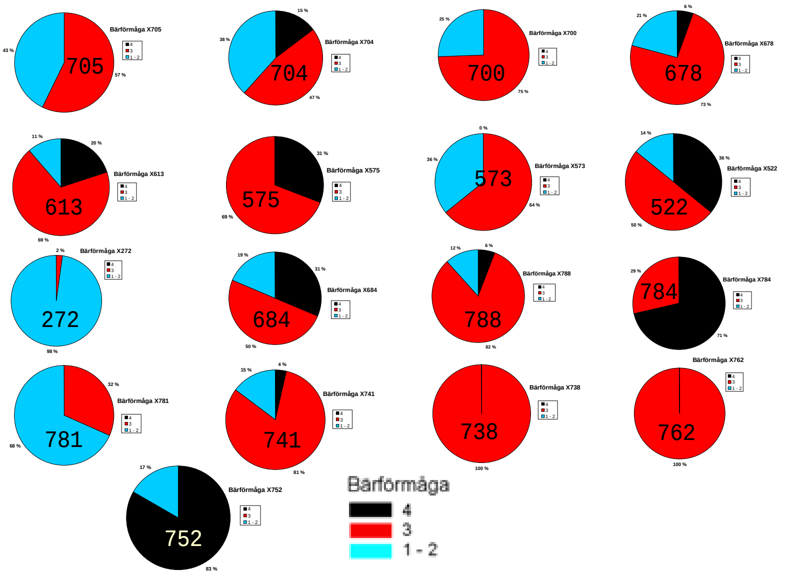

Figure 5. Bearing capacity class statistics from the roads surveyed in 2002 in Gävleborg County

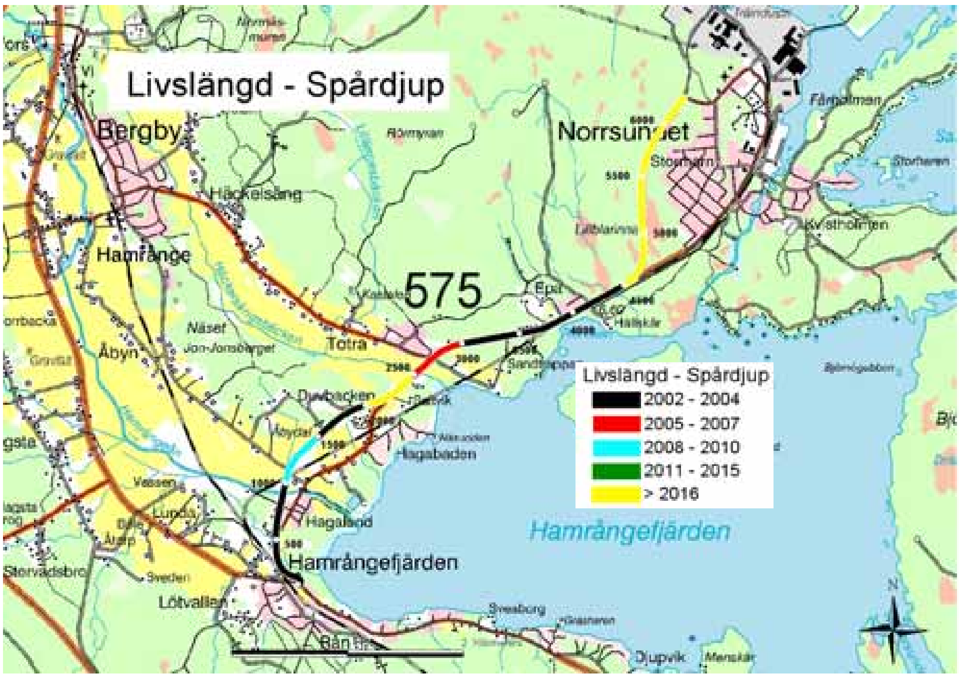

Figure 6. Example of lifetime depending on rut depth on road 575 in Gavleborg county

SURVEY DATA ANALYSES ON GRAVEL ROADS

BEARING CAPACITY

The analyses of the bearing capacity are based on drainage, structural evaluation with ground penetrating radar (GPR), surface curvature index (SCI) and base curvature index (BCI) from FWD results. The SCI is a measure of the stiffness of the upper part of the structure, D0-D200 and the BCI is a measure of the stiffness in the lower part of the structure, D900-D1200. A classification has been done with three classes for each parameter. The lack of bearing capacity for gravel roads is defined as an index of the classified parameters named above made up from the following formula:

Bearing Capacity Problem Index =

(0,25*drainage + 0,33*SCI + 0,27*BCI + 0,45*structural GPR) * 10

Then three classes for the index are defined as follows:

- Class 1, no deficiencies or minor deficiencies -Index between 0–19
- Class 2, evident deficiencies - Index between 20–29
- Class 3, major deficiencies - Index between 30–39

The results from every project are presented on paper in longitudinal profiles but they were also shown on GIS maps in an interactive Power Point presentation.

CONCLUSIONS

The 5-year survey has produced a lot of valuable data, which can be used for planning, rehabilitation design and statistical analyses of the functional and structural condition of the road. This method has also proven to be efficient in evaluating where and what type of bearing capacity problems can be found in the road network. These advanced bearing capacity and remaining lifetime analysis results produced for this project in Region Mitt were made possible through the development of Road Doctor™ software.

This paper is an executive summary of the paper “Network and Project Bearing Capacity Surveys and Analyses Using Modern Techniques” by Johansson, Saarenketo and Persson that will be presented at BCRA´2005 Conference in Trondheim, Norway.

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