ROADEX
Implementing Accessibility

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ROADEX BENEFITS AND SAVINGS - ACHIEVING MORE WITH LESS

A Report on the potential benefits and savings that can accrue in using ROADEX policies and technologies

ROADEX benefits and savings - achieving more with less

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Abstract

This report, "*ROADEX benefits and savings – achieving more with less*", summarizes the findings of the research projects executed during the ROADEX project 1998 – 2012. It is written for engineers, politicians and decision-makers with an interest in the sustainable management of low volume road networks in a time of extreme budgetary pressures. It describes the savings possible if the policies and techniques recommended by ROADEX are implemented.

The key practices and policies for sustainable road condition management policies in the future will need to be a) better drainage maintenance, b) focused problem based rehabilitation design, c) monitoring of road condition and seasonal change, and d) the use of road friendly vehicles. When a good combination of these can be used in everyday road management, the savings to roads administrations could be of the order of 50 %, or more, compared to present day costs. This means that the limited funding resources currently available to roads organisations can be used to even greater effects on the road networks, and that the current trend of slowly deteriorating roads can be stopped.

The report gives examples of the economic benefits of improving the drainage of roads and keeping the drainage in good condition thereafter. This is particularly important for the thin bituminous paved low volume roads networks of the Northern Periphery which are highly susceptible to poor drainage. The potential savings for keeping the road drainage of these roads in good condition can be up to 2000 €/km/year.

Focused road strengthening design can offer further savings to roads owners. New road survey techniques can reduce rehabilitation costs by 15-50 %, and costs over the lifetime of a road can be cut by 50 %. New information is given on the most economical solutions for roads on peat and how to widen roads.

The report also provides information about the importance of road condition monitoring and good management policies to combat problems due to seasonal changes.

Finally the report provides information on the benefits of the use of new road friendly heavy vehicles. These vehicles have special tyre configurations and tyre pressure systems that spread their axle loads to a wider area and prevent damage to pavements when they are at their weakest. Additionally these vehicles can reduce health issues in drivers due to vibration.

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1. INTRODUCTION

Funding of the condition management of European road networks, and especially low traffic volume roads, has been constantly decreasing over the last decades. When the first ROADEX project started in 1998, one the key challenges for road owners was how to keep the condition of their rural road networks at such a level to ensure safe roads and the sustainable development of local livelihoods. In 1998 road engineers had two options to deal with the gap between reducing funding and the increasing demand for road performance: a) blame the politicians for all the problems because of reduced funding, or b) look into the mirror and start to improve the productivity and efficiency of road condition management policies and practices.

ROADEX has executed numerous research and pilot projects since it first started in 1998-2001, all with the common general goal of “how to do more with less”. A number of excellent findings with a high potential to increase productivity and increase savings have been made without compromising quality. Results have been published in a range of reports and the goal of this report is to summarize their benefits and savings by example case studies calculations wherever possible.

Unique in the ROADEX project has been that, in addition to searching for new solutions for road diagnostics, maintenance and strengthening, the project has also considered if investments could and should be made to heavy vehicles to make them more road friendly. The results of these surveys and pilots have been very promising and have given new options for road owners and local businesses to manage their roads and transportation projects.

Finally, an important area where authors could not calculate the economic benefit directly was in health issues and how poor quality roads can affect drivers´ health. ROADEX has also published results on the relationship of poor quality roads and the increasing risk for traffic safety. When the economic benefits or impacts of these two issues can be calculated in the future, it is likely that these will be the greatest motivations for governments to invest in measures to improve and keep roads in a decent condition.

2. PRINCIPLES

The key word in the ROADEX saving philosophy is **focus**, and in particular focusing on a range of elements in turn using modern technologies. This means in practice answering four questions: what, where, why, and when.

1. **Focus** on the problem diagnostics, ie understand the reason for the problems. Low volume roads do not suffer or deteriorate evenly, and the lifetime of a road is as a consequence defined by its weakest link. The ROADEX project has shown that there are numerous reasons why road sections fail. Some of them are cheap to deal with, but others need more expensive measures. This means that it is necessary to focus on repairing the underlying reasons of the road problems, instead of dealing with the symptoms. This will ensure that solutions will work and not be temporary fixes to problems that will reappear soon after rehabilitation is finished. Understanding the scope of the problem better can sometimes lead to innovative solutions, for instance the use of road friendly trucks with reduced tyre pressures instead of expensive road repair.
2. **Focus** on the weakest road sections in strengthening measures, especially where funding is limited. Past practices usually involved the rehabilitation funding being spread more or less over the whole road section which meant in practice that the weakest sections did not get sufficiently strong enough structures. Good and strong sections were strengthened without any reason. In addition the start and end points of strengthened sections had long “security distances” mainly because the positioning system was not accurate. Currently, thanks to new and accurate GPS technology, this is not a problem anymore and savings can be achieved by improving the accuracy of design and construction.
3. **Focus** on the correct timing. As stated earlier the remaining lifetime of a road network, and the individual road sections in it, can vary substantially. This means that it is not economically sound to immediately strengthen a road section where the measures will needed later, particularly where the general funding for low volume roads is limited. ROADEX calculations, given later in this report, clearly show that the most economical way, after investing in drainage improvement, is to start to lift the bearing capacity of the worst sections in the road, step-by-step, e.g. at 6-8 years intervals for a 20 years life span,. The traditional way of thinking of fixing everything on the road while the contactor is there is not always economically justified.
4. **Focus** on preventative maintenance. Once a road and road drainage has been improved the greatest mistake is in planning maintenance measures based on the average lifetime of the drainage system. This is because the weakest sections that control the lifetime of the road need almost constant maintenance. Waiting until 50 % of the drainage is in poor shape means that the lifetime of the pavement is already reduced by 50 %. In the future road organizations should, and will, react in response to even the smallest anomalous changes in road condition.

The reason that the policies and measures mentioned above have not been implemented earlier can be explained by the lack of suitable technologies at reasonable price. However thanks to recent developments in data processing, data storage capacity, and better positioning systems, modern road survey and monitoring methods are increasingly cost effective, and their results easy to use on road management projects.

The increasing levels of heavy loads on rural roads can also give rise to a 5th focus:

5. **Focus** on load management. ROADEX research has shown that in many cases the most sustainable solution to keep a road in good condition is not investing in road structure improvement but investing in road friendly truck technologies. Many times 80-90 % of the rutting and pavement damages on rural roads are caused by only a few heavy trucks, with super single tyres and high tyre pressures, using the road on the weakest days during spring thaw weakening or after freeze-thaw cycles. Restricting these roads to trucks with road friendly tyre and tyre pressure solutions will have a major impact on keeping the road condition good with limited funding.

3. STRENGTHENING DESIGN

Traditionally the only solution to a road with performance problems is strengthening the road. This has been, and still is, all too often carried out using a one “patent” solution to the whole road without seriously thinking if this is wise or not. A typical example of this is the “additional new overlay” solution. ROADEX offers new ideas and design solutions that can be used in these projects. Some of these are presented in this chapter together with information on their potential savings compared to traditional methods.

3.1. FOCUSING STRENGTHENING MEASURES TO EXACT LOCATIONS

The ROADEX method of ”precise design” is a method which addresses the underlying reasons for the problems on a road through a process of detailed diagnosis of the road and its surroundings. The method identifies which sections of road have failed, or have been performing clearly worse than other sections and based on this analysis, heavier rehabilitation operations can be performed only and exactly on the sections that have failed or are weaker. Those road sections that have been performing well are not rehabilitated “just in case”. A benefit of the method is that the old structures in the road can be recycled into the new one.

The use of the “precise design” methodology is now possible thanks to the latest developments in modern road surveys technologies and very accurate GPS positioning systems. Thanks to more powerful processors and data storage technology, as well as better software visualization packages, it is now possible to make an integrated analysis of all the collected data. This has also led to a better knowledge of structural and functional behaviour of roads.

As mentioned earlier, a key component for a cost effective and sustainable road rehabilitation or strengthening project is a reliable and precise road problem diagnostics system. This can allow a targeted analytical design based on the reasons for the damages and their exact location. The precise design system ensures that rehabilitation structures are designed to address the cause of the problem, and that design structures are optimized for the transportation needs of the road. Precise design can also save substantial sums of money since heavy rehabilitation structures are invariably expensive. For example, shortening a thick rehabilitation structure by only 1-5 metres will return all of the money used in better diagnostics and design. In addition the lifetime of the new road structure will be substantially longer as the road diagnostics will allow the design engineer to focus on the “weakest links” of the road.

The precise design of locations can also create savings if the subsequent construction operations can be directed exactly to the correct sections needing strengthening. Earlier, before the availability of the new accurate GPS positioning techniques, heavier rehabilitation structures were applied before and after the weak sections to ensure that the weak sections were strengthened. This meant in practice 20-50 m longer rehabilitated structures on both sides of the target length resulting in increases to the rehabilitation cost. Figure 31_1 shows a typical case of a typical low volume road in the ROADEX area needing strengthening, and the differences in the resulting lengths for different strengthening options due to the accuracies in the design process. Figure 31_2 shows that remarkable savings can be achieved by using focused design. For example, soil replacement structures can be very expensive such that their focused design and construction can lead to major savings.

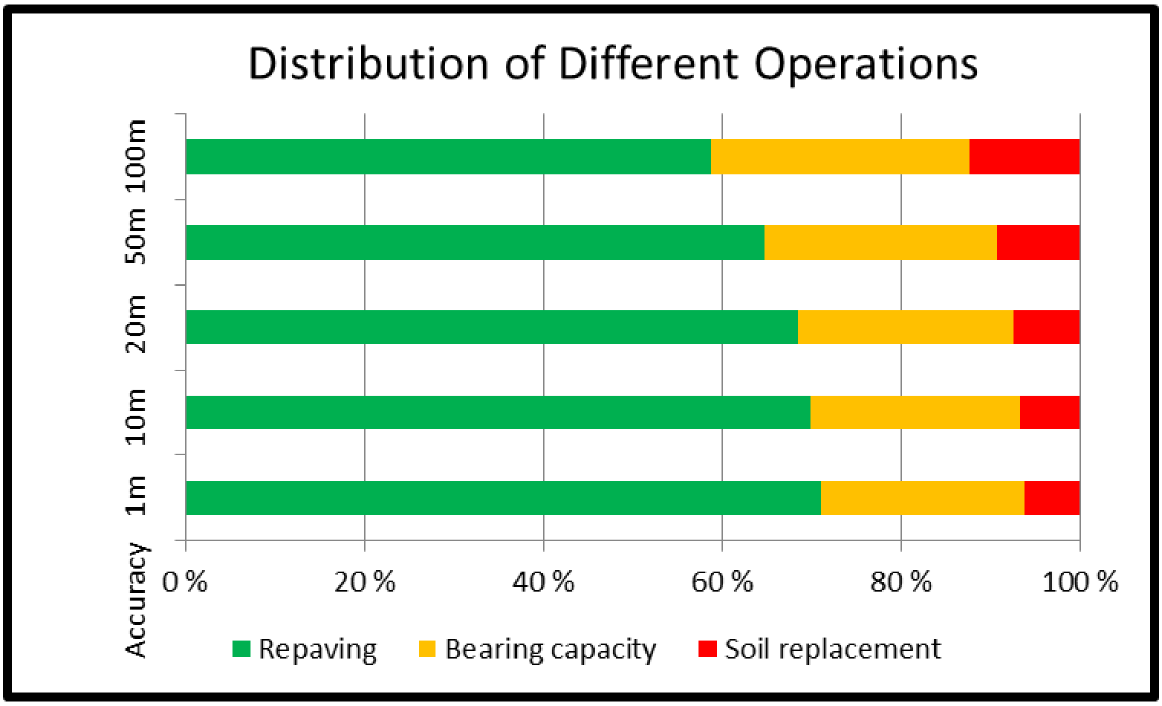

Figure 31_1. Relative share of the lengths of different operations depending on the accuracy of the design process: 1, 10, 20, 50 or 100m. The graph presents a typical strengthening project in the Northern Periphery area.

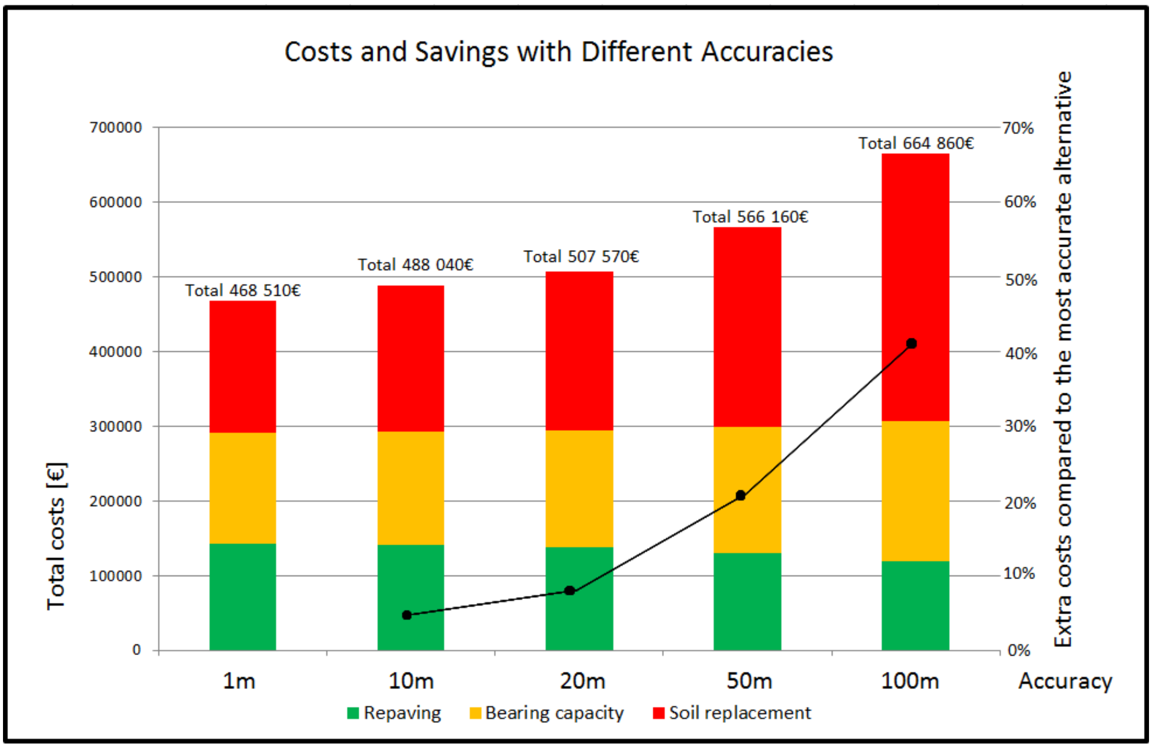

Figure 31_2. Comparing the costs of different operations if the accuracy in design process is 1, 10, 20 50 or 100m. The bars indicate the total costs of the various design options. The operations are shown in different colours. The black line and percentages presents the amount of savings that can be achieved with accurate design. The additional cost % is shown relative to the option for "1m accuracy".

3.2. “RIGHT IN PLACE” DESIGN OF STRUCTURES (TIMMERLEDEN CASE)

In addition to focusing exactly on the right locations, another source of major savings is optimizing the structural thickness, meaning that only the weaker sections get strengthened and that the strong sections are left as they are, or only get surface treatment. However this can only be done if there is enough information on the layer thicknesses and stiffnesses of the existing road structures and subgrade soils. Compared to traditional design methods based on visual evaluation and the designer´s experience, the ROADEX technique uses ground penetrating radar (GPR), falling weight deflectometer (FWD), digital video and laser scanner surveys. This makes survey and design costs more expensive. But when the total strengthening costs are calculated the ROADEX method is cheaper, both in the short and long term. In addition, by optimizing the use of non-renewable materials, the ROADEX method can also be more environmental friendly.

It is regularly claimed that modern diagnostics and design methods cannot be used in low volume road because budgets are so low. But the greatest relative savings can be achieved exactly on these roads. The benefits of the ROADEX road rehabilitation design method was demonstrated in a project carried out on the Timmerleden forest road in Sweden (Christoffersson and Johansson 2012). In this project detailed surveys, using GPR, FWD and digital video techniques, were first conducted on the existing road to assess the road condition and locate the weakest areas. This information was then used in an analytical design to calculate the structures needed to raise the bearing capacity to the target bearing capacity level. This rehabilitation proposal, made according to the ROADEX Odemark method, was then compared to the normal rehabilitation proposals made by three different consultants that had long experience on forest road design (Figure 32_1). The results showed that, in spite of higher costs for initial road surveys and design, the ROADEX method used was 14 - 51 % cheaper overall than the other proposals. A main benefit of the ROADEX design method is that it is possible to design optimal structure thicknesses “right in place” thereby avoiding over-dimensioning.

Dimensioning proposals for Timber road, length 5 km, width 4,5 m; layer thickness in millimeters

COMPANY	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000
Consult A																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	250	250	250	100	100	100	100	100	100	100	100	100	100	100	100	250
Sub-base																				
Ditch left																				
Ditch right																				
Consult B																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Sub-base																				
Ditch left																				
Ditch right																				
Consult C																				
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				
ROADEX method																				
Wearing course	150	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	250				200	200	200	200	200	100								100	100	100
Sub-base																				
Steel reinforcement						10	10													
Ditch left																				
Ditch right																				

Figure 32_1. Rehabilitation plans made by three consults compared to ROADEX design method. Note that the non-ROADEX plans used almost the same type of structure type throughout the road.

A summary of the four proposals is presented in Table 31_1. Comparing these it can be seen that the ROADEX design method was as a whole the cheapest (48 546 €), although it included field survey and design costs 17-34 times more than the other proposals. The strengthening price of the ROADEX design method was 9.71 €/m. The price of the proposal from consultant A was 11.18 €/m (15% higher than ROADEX proposal). The price of the proposal from consultant B was 11.06 €/m (14% higher), and the price of the proposal from consultant C was 14.63 €/m (51% higher). The prices shown also include an estimate of the environmental costs of producing the calculated volumes of aggregates (CO_2 emissions, 0.15 €/kg).

Table 31_1 Cost comparison of different design methods in Timmerleden road in Sweden

	Consult A	**Consult B**	**Consult C**	**ROADEX method**
Aggregates (10€/m3)	51130	50880	67500	35260
Steelreinforcement (4€/m2)	-	-	-	-
Ditching	?	?	?	?
Field survey & design	500	250	250	8500*
Environmental costs (0,15€/kg)	4272	4404	5640	2946
Total (€)	55902	55534	73390	48546
€/m	11,18	11,06	14,63	9,71
	115 %	**114 %**	**151 %**	**100 %**

The benefits of the ROADEX design method can be seen to be even greater if long term yearly costs are also calculated. This is because the lifetimes of the other design options are shorter as they did not use sufficiently strong structures on the weakest sections (Figure 31_2). To give an idea of the long term benefits possible, the costs of ROADEX design method were discounted as yearly costs. For a road lifetime of 8 years, the discounted costs per year would be 7,666.47 €. If the lifetime is longer, for example 20 years, the discounted costs per year would be 3,976.02 €. This means in practice that a 3 year longer lifetime would pay back all the ROADEX design costs.

The ROADEX method was also found to save natural resources and reduce emissions of carbon dioxide. It was considered that the method could produce even better savings in larger road rehabilitation projects, or in several smaller projects in the same area, where the unit costs of field surveys and design could be substantially decreased. In these circumstances it was considered that the possibilities of saving natural resources and money, and reducing the emission of carbon dioxide, would be even better.

Figure 31_2. Example of Timmerleden forest road before (left) and after (right) rehabilitation. In this section the road had been strengthened only a few years before but had failed soon after as the structures used were too thin.

The ROADEX method of analytical design based on surveyed road condition data can also provide other advantages:

- Decisions on design thicknesses can be objectively based on measured data
- Over dimensioning can be avoided
- The design method is easy. Previous years of experience in using the method is not required
- The finished rehabilitation can be checked objectively

3.3. FOCUSING THE TIME OF THE INVESTMENTS

Funding is in most cases the key limiting factor in rehabilitation projects. When faced with this case the normal reaction for the road owner/engineer is first of all to save in the design and then save in the structures, i.e. design the strengthening of the road with thinner and weaker standard structures. However ROADEX project results clearly show that this “face lift” policy is not an economic solution in the long term.

Carrying out a “face-lift” does not however diminish the fact that the money is still limited to improve the road. This can only be solved by designing a longer term solution. In another words the road is kept in good condition for the duration of the design period by 1) focusing on the problem diagnostics, 2) choosing optimal structures for each road section, and 3) optimizing the timing of the different operations. It is not needed to repair whole road at the same time.

A good solution where there is not enough money at the beginning of a project is the time based “step-by-step” rehabilitation. This can offer a cheaper option to the “face-lift” plan and allow the necessary investments to be phased over a number of years. In order to demonstrate this approach on long term costs ROADEX made experimental calculations of different structural options based on real data collected in the Pajala mine road project (Matintupa et al. 2012).

In this project the road was first classified into five risk classes based on the following risk classification used in ROADEX projects. This risk method of analysis helps to design the “right operations in the right places” and to avoid “safe design” whereby operations are planned in places where they are not needed.

Risk class 1 - Strong road section, no risk major for immediate failures. Pavement fatigue will follow normal road lifetime prediction models

Risk class 2 – Relatively strong road. Road damage will appear quickly only in extreme loading conditions or due to poor drainage maintenance etc. Light strengthening recommended for this class.

Risk class 3 – Adequate road section. Road damage will mainly appear during particularly bad spring thaw weakening periods. Strengthening recommended.

Risk class 4 – Weak road section. High risk for road failures especially during the spring thaw weakening period. Strengthening strongly recommended.

Risk class 5 - Extremely weak road section. Severe damages can be expected immediately after heavy haulage starts. This class should be strengthened immediately.

Once the risk classes had been established a list of different rehabilitation strategies were costed and a summary of these operations is presented in Table 33_1. The lifetime of each road structure was calculated using “PMS Objekt” software on the bound layers and at the foundation level using a target lifetime of 20 years. If this target lifetime was not achieved after the first rehabilitation, a repaving of 50 mm was laid where required. Calculations were performed for three different heavy traffic flows of 100, 250 and 500 vehicles per day. Finally, the effects of the different operations on the total costs and average annual costs over the next 20 years were examined. The costs were calculated as total costs and discounted annual costs. The costs per kilometre were also calculated.

Table 33_1. Structural options used in the long term cost calculations.

0	No improvements
0+	New pavement 50mm on whole road, repaving on whole road
1	New pavement 100mm on whole road
2	Milling of old pavement, 100mm of new base course gravel, 100mm of new pavement on whole road
3	Milling of old pavement, 200mm of new base course gravel, 100mm of new pavement on whole road
4	Improve risk class 5 road sections up to risk class 4 (bearing capacity ~215MPa) with rest of road given 50mm new pavement
5	Improve risk class 4 & 5 road sections up to risk class 3 (bearing capacity ~240MPa) with rest of road given 50mm new pavement
6	Improve risk class 3, 4 & 5 road sections up to risk class 2 (bearing capacity ~275MPa) with rest of road given 50mm new pavement
7	Improve risk class 2, 3, 4 & 5 road sections up to risk class 1 (bearing capacity ~300MPa)
8	New pavement 50mm on whole road, later 1-2 repaving on the weakest sections

Repaving = 50 mm new pavement

These calculations showed that the most economical solution was structural option 4, where initially the money was used to repair only the poorest sections while rest of the road was paved with a new pavement. The most expensive solution was option 3, where one standard strong solution was used. This involved milling away the old pavement, adding 200mm of new base course gravel and 100mm of new bound base + pavement on the whole road. The cost difference between these two options was 63-86% depending on the traffic volume. The total cost and annual cost of each option are compared in Table 33_2.

Table 33_2. Comparisons of the long term (20 years) costs of different structural options. Total costs, discounted costs, total costs/km and difference in cost from the cheapest of each option.

Heavy vehicles	100				250				500			
	Total cost {Mill. SEK]	Discounted cost/year {Mill. SEK]	Total cost/km {Mill. SEK]	Difference in cost from the cheapest [%]	Total cost {Mill. SEK]	Discounted cost/year {Mill. SEK]	Total cost/km {Mill. SEK]	Difference in cost from the cheapest [%]	Total cost {Mill. SEK]	Discounted cost/year {Mill. SEK]	Total cost/km {Mill. SEK]	Difference in cost from the cheapest [%]
Option 0	0	0	0	-	0	0	0	-	0	0	0	-
Option0+	21,9	1,8	1,09	48 %	25,3	2,0	1,26	45 %	29,8	2,4	1,48	42 %
Option 1	21,7	1,7	1,08	47 %	22,1	1,8	1,10	27 %	27,7	2,2	1,38	32 %
Option 2	25,7	2,1	1,28	74 %	30,0	2,4	1,49	72 %	33,9	2,6	1,69	57 %
Option 3	**27,6**	**2,2**	**1,37**	**86 %**	**32,1**	**2,6**	**1,60**	**84 %**	**34,2**	**2,7**	**1,70**	**63 %**
Option 4	**14,8**	**1,2**	**0,74**	**0 %**	**17,5**	**1,4**	**0,87**	**0 %**	**21,0**	**1,7**	**1,05**	**0 %**
Option 5	17,0	1,4	0,85	15 %	20,7	1,7	1,03	18 %	24,4	2,0	1,21	16 %
Option 6	23,2	1,9	1,16	57 %	26,8	2,2	1,34	54 %	29,9	2,4	1,49	42 %
Option 7	22,3	1,8	1,11	51 %	25,3	2,0	1,26	45 %	28,6	2,3	1,43	36 %
Option 8	16,4	1,3	0,81	11 %	19,0	1,5	0,95	9 %	15,3	1,7	1,05	0 %

The most expensive (a common rehabilitation along the whole road)

The cheapest (focussed rehabilitation only where it is needed)

The bearing capacity distribution achieved by each option was also calculated in addition to cost. Figure 33_1 compares the bearing capacity distribution of the most expensive and the cheapest options. This distribution shows that using option 3 will result in more than half of the road being over-dimensioned.

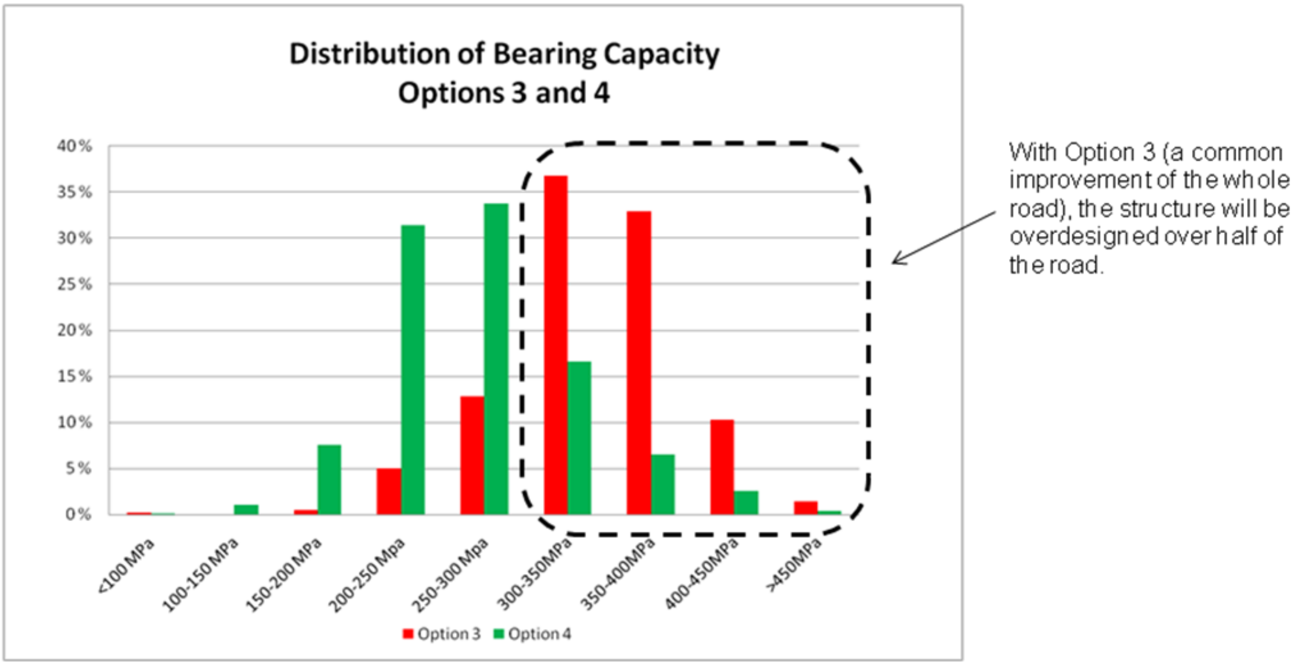

Figure 33_1. Bearing capacity distributions of structural options 3 and 4.

Figure 33_2 shows the total costs of some selected options broken down into year of investment. This shows that options 3 and 7 (heavy operations for the whole road section) invest fully at the beginning of the project, and assume that no more measures are needed later. On the other hand the investments and operations for options 0+ or 4 are divided over several years and only 10 million SEK is needed in the beginning.

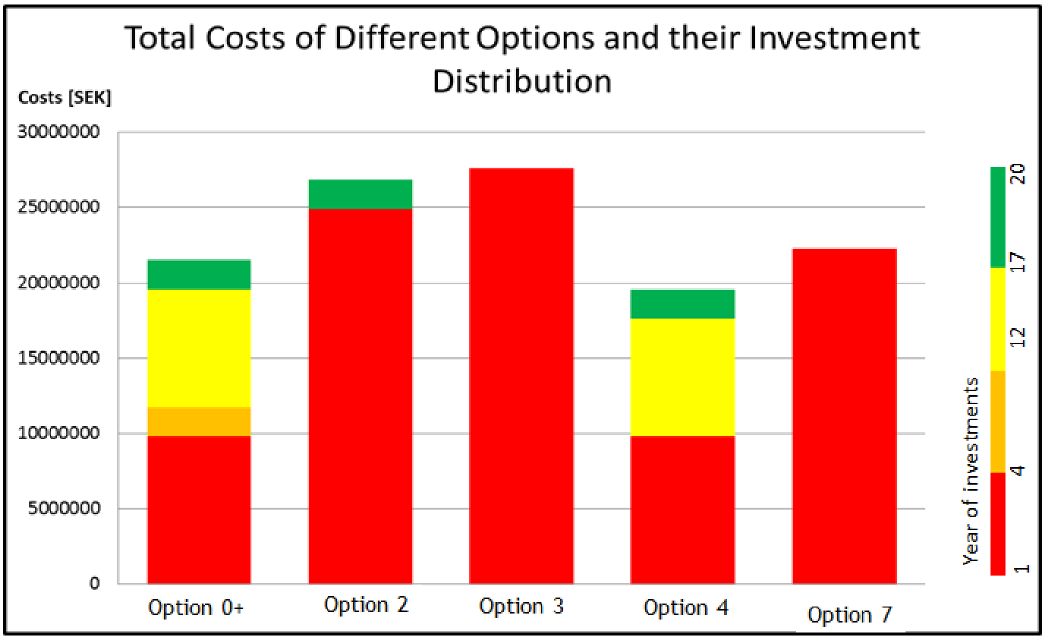

Figure 33_2. The total costs of different options and their distribution over a lifetime of 20 years. The red colour represents the amount of money that needs to be available immediately.

3.4. ROADS ON PEAT

The ROADEX method of precise design can also be used for roads crossing areas of peat. As with any strengthening of roads, especially heavy rehabilitation or strengthening, knowing exactly where the problem lies and where do deal with it can bring significant savings to a "one solution fits all" approach. With this in mind the ROADEX website reports four case studies involving roads on peat: the N56 and N59 in western Ireland, and the B871 and B876 in Scotland.

3.4.1. N56 and N59 in Ireland

The ROADEX IV project carried out two demonstration road risk assessments in Ireland on public roads over peat using the standard data collection surveys of GPR using two antennas (an air-coupled 1.0 GHz horn and a 400 MHz ground-coupled antenna), laser scanner, a digital video with GPS coordinates, and a FWD survey with test points every 50 metres along the road (Figure 34_1). These assessments also allowed the identification of locations of areas of peat and soft soils below the road. The two projects were:

- A 10km section of the N59 Newport to Mulranny in County Mayo
- A 10km section of the N56 Drumnaraw to Cashelmore in County Donegal

In the risk analysis of the 10km of the N59, "Class 2" and "Class 3" risks were predicted for 1705 m of the road section (16.5%), and 8569m of the road (83.5%) was classified as having a reasonably well working structure with a rating of better than "Class 2". The N59 results therefore meant that 83.5% of the road section could be safely left in place when road strengthening measures were being planned. This knowledge offered huge savings over the former methods of assessment which were generally based on a visual survey of the road surface for the identification of any structural problems.

The risk analysis of the 10km of the N56 in County Mayo was carried out in a similar fashion and identified that "Class 2" and "Class 3" risks were predicted for 6092m of the road section (39%), and that 9384m (61%) had an assessment of better than "Class 2". This again offered significant potential savings on proposals based on the former visual survey methods.

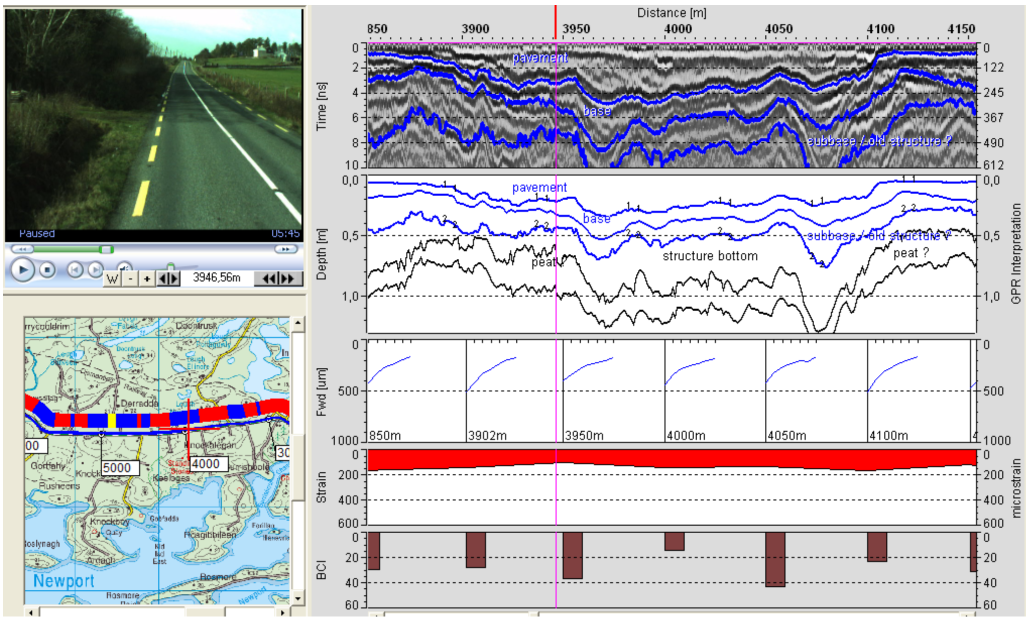

Figure 34_1. "Road Doctor" output screen from a section of the N59 built on peat, but where the effect of weak peat subgrade has been compensated with a thicker bituminous pavement.

3.4.2. B871 and B876 in Scotland

The B871 in central Sutherland was a ROADEX test road since 2001. The road was identified for ROADEX collaboration in 2001 when it was planned to use the road as a haul route for timber. The cost of improving the 55km, 2.7m wide road to a standard suitable for the heavy timber traffic was estimated to be over £10 million, a sum not affordable to the local roads authority. The Highland Council and the Forestry Commission were however partners in ROADEX and agreed to use the road as a ROADEX test bed to trial low cost remedial measures, including works over peat. These included removing the grassy verges from the road, the use of geogrids in remedial surfacing layers, and a lightweight replacement of an embankment that was settling into peat.

A key issue in all rehabilitation of roads on peat is to "do no more harm" to the existing hydrological balance that has built up between the road and underlying peat over time. This means only careful drainage measures should be carried out (if any) so as to preserve the existing water table, and not to add any new loads on to the peat unless their impacts can be accepted. An innovative design of lightweight waste tyre bales was used in this project to replace a section of road that had sunk into a 6m deep underlying ravine of peat. (6m deep). This section was frequently covered by water up to 200 mm deep.

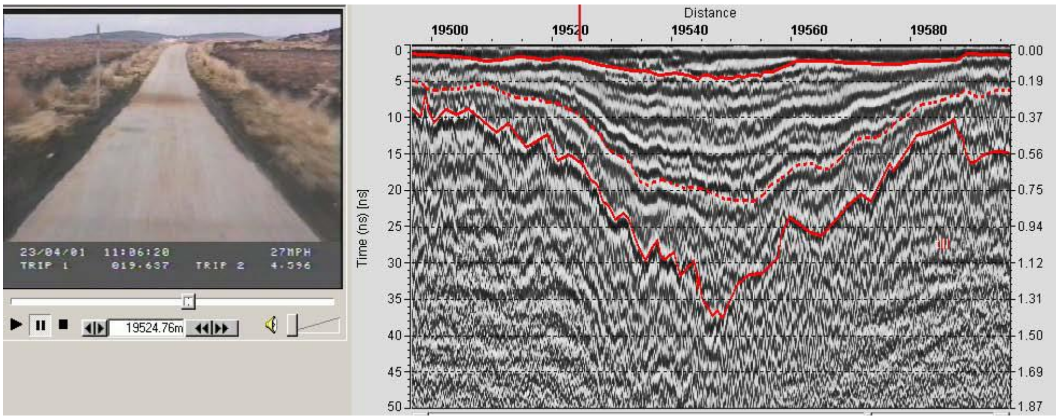

Figure 34_2. GPR profile along the road section showing the road construction and ravine of peat. The pavement is 0.8 m thick in the deepest section.

The design selected involved the removal of the existing sunken road construction over the peat hollow and its replacement with a lightweight embankment of waste tyre bales. The overall length of the project was 100 m with tyre bales being used over the central 55 m.

Figure 34_3. Photograph of the lightweight replacement embankment under construction

The B876 at Killimster Moss was one of the first sites where ROADEX exchange of best practice was implemented in a full scale road test. This section of road was built in 1930 over blanket bog using a reinforced concrete slab, and later this was paved with bituminous layers and later widened with traditional structures. By the 1990´s the road had started to fail under heavy traffic and it was decided to strengthen and widen the road using steel grids using experience from the Nordic Countries.

Figure 34_4. Photograph of the road surface condition on the Killimster road in 1999.

Due to limited funding the design life of the strengthened structure was agreed to be 8 years, and the solution was requested to be as cheap as possible. A main goal of the strengthening design was not to increase the embankment load any further so as to trigger further settlements. It was therefore decided to remove the bituminous layers down to the top of concrete and replace with new.

The works were constructed in 2000 and performed acceptably over the specified 8 years lifetime, although transverse cracking reappeared in the later years. The section was monitored again in 2011 as part of the ROADEX IV project to investigate how well the design had performed since construction. The surveys showed that the structure had performed better on the sections where there were bituminous layers beneath the steel reinforcement. The FWD survey showed that there were problems with load distribution where the road structure changed thickness due to the shape of the underlying concrete slab. Sections where the steel grid had been installed deeper in the road structure (ie at depth of 250 mm as recommended by ROADEX) performed better than when the grid was installed higher up, confirming the benefit of the high tensile strength of a steel grid when it is optimally used. Installing steel grids deeper was discussed during the design phase but could not be done because of the higher cost of the work, and lack of available funding.

Figure 34_5. .Strengthening the Killimster Moss road using a steel reinforcement structure in 2000 (left) and Killimster Moss road after 11 years in 2011 (right). ROADEX tests showed that those sections that had failed were those where steel grids were installed directly on the top of old concrete road.

4. DRAINAGE MANAGEMENT

4.1 DRAINAGE AND PAVEMENT LIFETIME

ROADEX research has shown that road drainage is the most significant individual factor affecting the long term performance of a road. Drainage has a great influence for example on bearing capacity, frost heaves and permanent deformations of the road, and sections with poor drainage can always be considered as the “weakest links” when discussing pavement lifetime.

Pavement lifetime can be described as a function of the annual increase of roughness and rutting values, as well as cracking. If the drainage can be kept in good condition, the annual rut depth growth will be significantly lower. This means a longer pavement lifetime, and at least 20-35% savings in annual paving costs.

To demonstrate the potential savings that can be achieved with good drainage, ROADEX carried out a range of calculations on the effect of road drainage to pavement lifetime (Figure 4_1) This was done using a typical road pavement structure used in Nordic countries, and typical traffic volumes. Calculations were carried out using PMS-object software based on linear elastic theory. Figure 4_1 shows that where the drainage is in poor condition, the road is more susceptible to damage the thinner the pavement. Normally in Nordic countries the pavement thickness is less than 100 mm. As an example, if the thickness of the bound layers is 80mm, the rutting increase is about 1.8mm per year when the drainage is poor. In this situation the lifetime of the road is about 10 years, and annual paving costs 5200 €/km. If the drainage can be improved to good condition, the rutting increase can be halved and lifetime doubled, resulting in savings of 35% in annual paving costs.

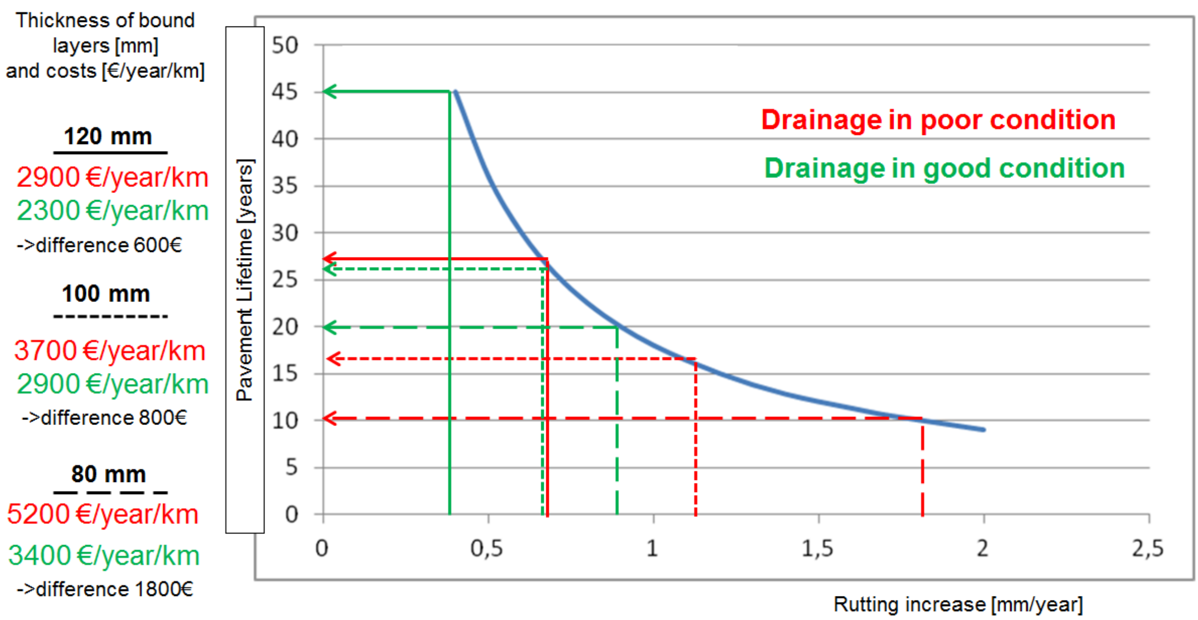

Figure 4_1: The effect of drainage on pavement lifetime, rutting increase and annual costs when the bound layer varies between 80-120mm. Calculations are based on PMS Objekt software and linear elastic theory with AADT 500 (includes 5% heavy traffic). The thickness of unbound layers is 620mm.

In practice the actual picture on Northern Periphery roads is even worse. Linear elastic theory can explain rut increases roughly up to 2 mm/year, but ROADEX field demonstration projects have shown that the poorest road sections can have rutting increases as high as 3mm/year, or even more. In these cases the road is suffering also from permanent deformations due to poor drainage. Figure 4_2 shows a case from Finland where the annual rut increase in sections with poor drainage was more than 3 mm/year. The map shows that the other sections of the road are following the linear elastic theory model really well with a rut increase of less than 1 mm/year. But the pavement lifetime of the whole is however defined by the 10 % weakest sections.

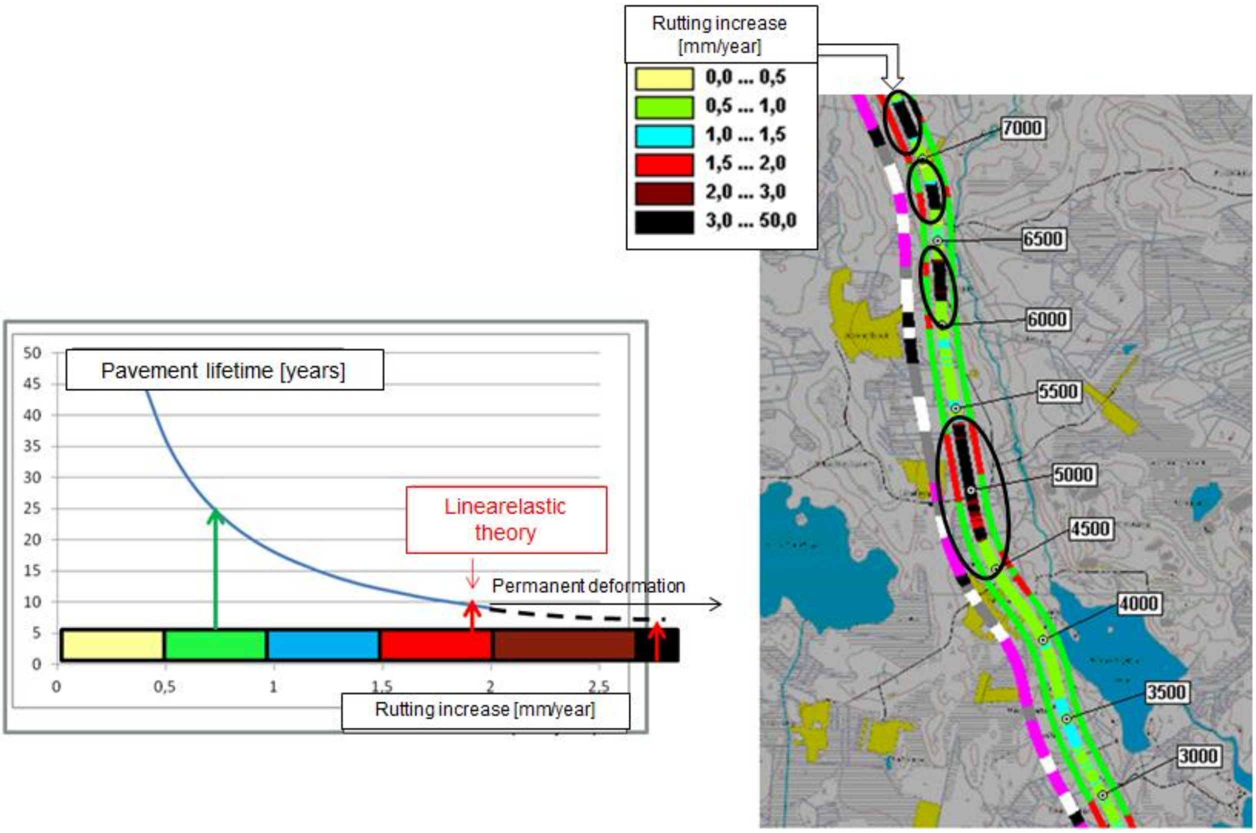

Figure 4_2. Rut depth increase mm/year in road 78 in Finland (shown in the middle line on the road) and its effect on pavement lifetime. In the "green" road sections the pavement is performing according to linear elastic theory, but not in the "black" sections (circled) which have rut increases of more than 3 mm/year. Here permanent deformation due to drainage problems is also adding to the rutting.

In summary it can be stated that the importance of a good drainage system is especially high on road sections with a thin pavement. A rough evaluation based on Finnish data shows that by improving drainage and making the pavement slightly thicker the pavement lifetime can be extended from the present 10-15 years to 20-40 years. Based on this, the potential savings can be 1000-1500 €/km/year, and in the optimum cases even 2000 €/km/year. This means in the Finnish public road network there are potential annual savings of 40 – 60 million €, or more.

The ROADEX project has also identified the special locations in road drainage systems where poor performance can have a major effect on road damages. Good examples of such locations are private access roads where missing, clogged or frozen culverts cause water to infiltrate into the road structures, causing further frost damages and permanent deformations. This can be seen in the ROADEX follow up surveys on road 934_3, where more than 50 % of the frost damages on the road could be related to private access roads. This problem could be found in all ROADEX partner countries but in Finland it was especially common because the maintance of private access road culverts were the responsibility of the the owners of the private roads. These owners do not necessarily have the resources, know how, or technologies to keep the culverts open. In other Northern Periphery countries the maintenance of the culverts below private access roads are the responsibility of the road contractors, but even in these countries more attention should be paid to better maintenance (Figure 4_3)

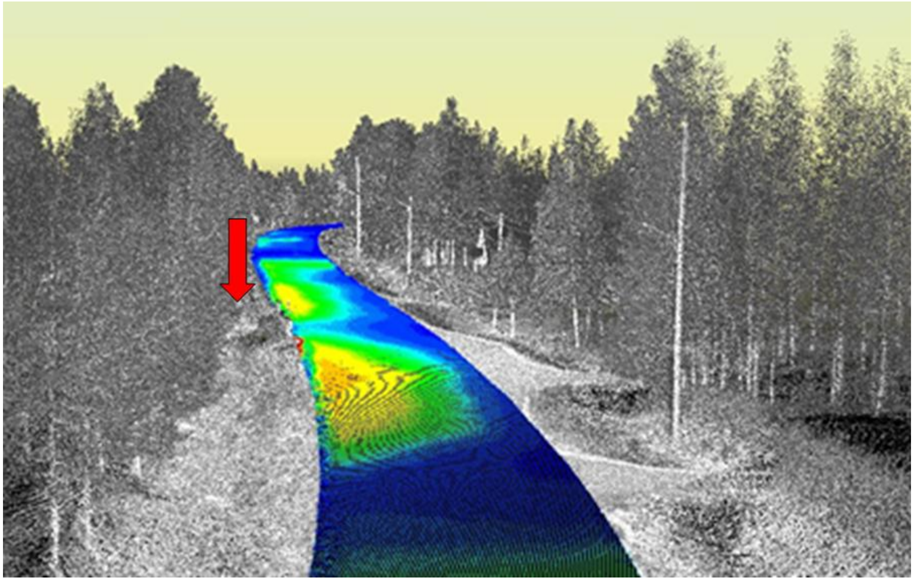

Figure 4_3. Screenshot of a clogged private access road culvert causing 100 mm differential frost heave (orange colour) to the road on both sides of the culvert, an example from Northern Sweden.

4.2 PROFITABILITY OF DRAINAGE IMPROVEMENT AND MAINTENANCE

The big problem with drainage maintenance is that it is normally carried out at predetermined time intervals, e.g. every 8 – 12 years. However cost effective drainage management may require that the “weakest link” sections need to be cleaned every second year, and if this is not done the pavement lifetime can be affected. With this background, discussions have arisen on how often drainage improvement measures could be taken while still keeping road life cycle costs profitable.

To clarify this question the ROADEX II project carried out a range of experimental life cycle cost analyses using a drainage improvement cost of 4,100 €/km and a pavement replacement cost of 35,000 €/km (lifetime ratio 0.117). The results of this analysis can be seen in Figure 42_1. This shows that by improving/maintaining the drainage it is possible double the lifetime of a road from 10 to 20 years, and that drainage maintenance can be done every second year and still be profitable, even with a discount rate as high as 8 % (as used in Norway in 2005). If the increase in lifetime is only 50 % (i.e. from 10 to 15 years), and the discount rate is only 4 % (as used in 2005 in Finland), drainage maintenance can still be done every third year and still remain profitable. Normally there is no need to carry out drainage maintenance more often than this. It should be noted here that the calculations did not take into account increases in other maintenance costs due poorly working drainage, or the benefits of keeping the drainage in good condition. These costs should be calculated for a longer time than one pavement life cycle as frost fatigue due to high moisture content can affect the long term performance of road structures.

The calculations also showed that it is always worth evaluating the use of more expensive drainage improvement solutions than merely ditch cleaning. For example, a drainage improvement costing 8400 €/km to double the lifetime of a road at 4 % discount rate can still be profitable every 5 years, and have lower life cycle costs than without drainage renovation. Examples and experiences of heavier drainage improvement structures are presented in ROADEX IV reports (Hyvönen et all. 2012).

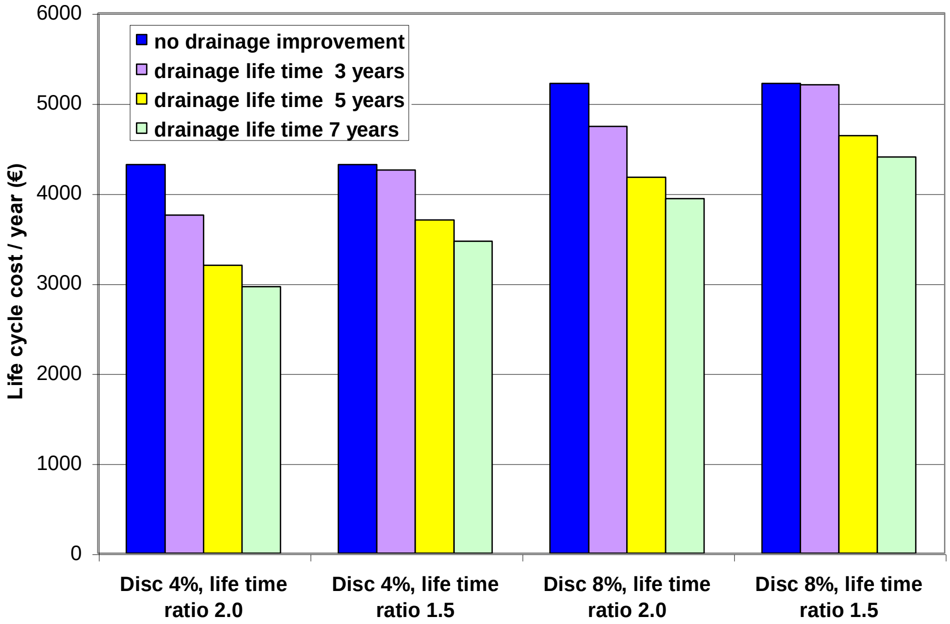

Figure 42_1. Example of life cycle cost analysis results showing the benefits of drainage improvements. In these costs, pavement rehabilitation costs have been calculated at 35,000 €/km and drainage improvement costs 4100 €/km. Results are presented using two lifetime ratios of 2.0 (10 to 20 years) and 1.5 (10 to 15 years and two discount rates (4 % and 8%).

In addition, as already mentioned, the work will be even more profitable as normally drainage improvement is only done on identified parts of the road.

4.3. POTENTIAL SAVINGS IN PRACTICE - CASE LAPLAND

Section 4.1 summarized the benefits of drainage improvement and increasing pavement thickness. Section 4.2 showed the benefits of keeping the drainage system in good condition. This section will show the potential savings of drainage improvement in practice through cost benefit examples from the Kemi, Kittilä and Rovaniemi maintenance areas in Northern Finland. The work was done during and after the ROADEX III project and was reported in detail by Saarenketo (2008).

The roads in each maintenance area were divided into three road classes for drainage analysis: main roads, regional roads and local roads (Table 43_1).

Table 43_1. Lengths of surveyed roads in Finnish Lapland.

	Lengths of roads [km]			
	Main	Regional	Local	Total
Rovaniemi	382	147	116	645
Kittilä	528	217	211	956
Kemi	167	253	363	783

As stated earlier in the report, the lifetime of a road section is controlled by its worst 10 % sub sections. Using this fact pavement lifetime factors were calculated for the surveyed roads based on rut depths and IRI values. The left hand chart in Figure 43_1 shows the ratio of the average rut depths of the worst 10 % drainage sections with the average values of the Class I drainage sections, and the right hand chart shows the similar relationship for IRI. ROADEX researches that have used this evaluation technique have shown that improving the problem drainage sections, and maintaining them in good condition, can increase the pavement lifetime by 1.5 - 2.0 times.

In the cases calculated in Finnish Lapland, the lifetime factor varied between 1 and 2 (Figure 43_1). This is an average of the whole road network, and can be even higher than 2 on particular road sections. For example in the Kittilä area, the results showed that the impact of poor drainage was significant on pavement lifetime. The calculated average pavement lifetime ratios (based on rutting) for the Kittilä area were 1.30 for main roads, 1.62 for regional roads and 1.35 for local roads. The greater the factors, the greater are the economic benefits of keeping the drainage in good condition, and the greater the annual paving cost savings are.

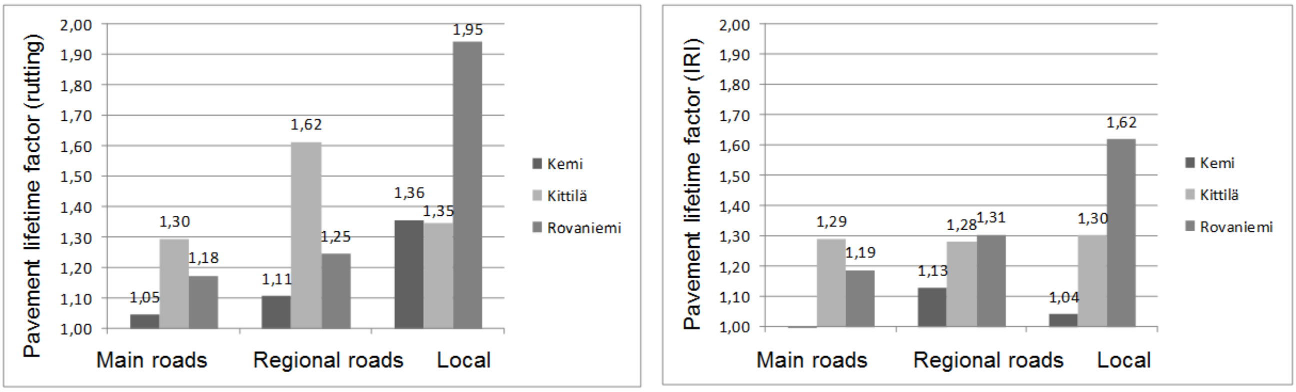

Figure 43_1. Pavement lifetime factors in the Kemi, Kittilä and Rovaniemi maintenance areas. Pavement lifetime factors based on rut values are presented on left side, and factors based on IRI values on the right side.

In order to calculate how much a well-functioning drainage can affect the life cycle costs of a pavement, it is important to know the costs of improving the drainage. Normally the costs of drainage maintenance are much smaller than those of repaving. Table 44_2 presents the detailed calculations from Rovaniemi, Kemi and Kittilä area in Finnish Lapland. This table shows If the drainage is improved, the potential savings in annual paving costs could be 9.5 – 20.2%. The greatest savings can be achieved in Kittilä maintenance area, where pavement lifetime factor are high, which means that drainage improvement would be the most profitable. Only the costs of repaving were taken into account in these calculations. Poor drainage also causes other damages, such as frost heaves, and repairing these damages cause costs as well. The repair of these is much more expensive than the costs included in the calculations. These cost benefit analyses used average pavement lifetimes from the Finnish road database and this might have been slightly too short. But, for instance in the Rovaniemi maintenance area, even if 1.5 longer pavement lifetimes were used, the annual paving costs would have dropped by only about 35% ,

Table 43_2. Potential savings for each area and road category.

Kemi	**Main roads**	**Regional roads**	**Local roads**	**All roads**
Annual paving costs (€)	2044000	1106000	915000	**4065000**
Annual paving cost if drainage improved (€)	1956000	1013000	710000	**3679000**
Savings (€)	88000	93000	205000	**386000**
Savings (%)	4,3	8,4	22,4	**9,5**
Kittilä	**Main roads**	**Regional roads**	**Local roads**	**All roads**
Annual paving costs (€)	2022000	527000	512000	**3061000**
Annual paving cost if drainage improved (€)	1663000	381000	400000	**2444000**
Savings (€)	359000	146000	112000	**617000**
Savings (%)	17,8	27,7	21,9	**20,2**
Rovaniemi	**Main roads**	**Regional roads**	**Local roads**	**All roads**
Annual paving costs (€)	1695000	530000	370000	**2595000**
Annual paving cost if drainage improved (€)	1505000	464000	314000	**2283000**
Savings (€)	190000	66000	56000	**312000**
Savings (%)	11,2	12,5	15,1	**12,0**

5. SPRING THAW WEAKENING MANAGEMENT

5.1 GENERAL

Seasonal changes and freeze-thaw cycles, and the damage they cause, are the most significant single factor affecting the road condition of the cold climate road networks of northern Europe, Asia and North America. According to different publications up to 80 % of the damages in the road network appear during winter and spring. Frost damage is visible in these roads as uneven frost heaves and longitudinal and transverse cracks, but above all as softening of the road structure and permanent deformation during the spring thaw period. In the worst scenario driving on these roads can be impossible.

Spring thaw weakening is the biggest problem on “unbuilt” gravel roads. For instance in Finland, almost half of Finland’s 28.000 km gravel road network suffers some form of spring thaw damage, and severe spring thaw damage has been found on 2-4 % of the road network.

The ROADEX project does not provide one single solution for the management of seasonal changes in different countries but proposes a road diagnosis based, customized solution for each road section that is based on: a) better maintenance, b) “right in place” rehabilitation, c) the use of road friendly heavy vehicles (CTI/TPC trucks) and d) monitoring of seasonal changes together with the use of load restrictions during the worst days during spring thaw. The proportion of each measure to be used on each occasion is based on the resources available and road user needs.

5.2 SAVINGS

The four ROADEX projects from 1998 – 2012 produced numerous research projects that focused on finding new and innovative solutions for road condition problems related to seasonal changes and spring thaw weakening. Some of the key findings and recommendations from the projects are presented in the following sections.

5.2.1 Drainage

Without doubt, the most cost effective and sustainable measure to reduce spring thaw weakening in the road network is improving the road drainage system and ensuring that it stays in good condition. Dry road materials and subgrade soils have high resistance against permanent deformation. Frost action requires extra water to be able to build ice lenses. Keeping road surface dry prevents Mode 1 rutting problems, and if the subgrade soil surface can be kept dry this can prevent Mode 2 rutting problems also. Drainage maintenance follow-up results from the Rovaniemi maintenance area in Finland showed hardly any spring thaw weakening problems on road sections where the drainage had been improved and kept in good condition (Peltoniemi-Taivalkoski and Saarenketo 2012).

However new laser scanners based analyses have shown that a surprisingly high number of observed spring thaw weakening sections were located around private access roads, which indicates that the culverts in these sections were clogged allowing water to infiltrate into the road structures making them fail (Figure 521_1). Figure 521_2 shows an example of the consequences caused by a clogged or missing private access road culvert. Flooding water has caused the inner road slope to become plastic and flow to the ditch blocking the water flow. The formation of large ice lenses that cause major potholes can also be a major traffic safety hazard.

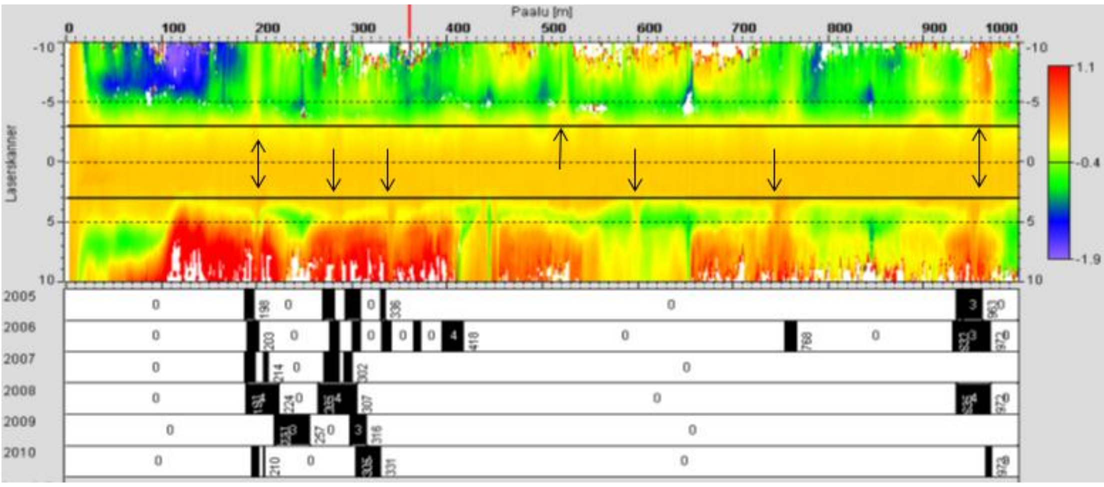

Figure 521_1. A laser scanner relative height map (above) and spring thaw weakening history 2005-2010 (below) from a gravel road in Finnish Lapland. These graphs shows clearly that spring thaw weakening problem sections are located the vicinity of private access roads pointed out by arrows in the laser scanner data.

Figure 521_2. Example of spring thaw weakening problem caused by a clogged and/or frozen private access road culvert (yellow arrow). The red circle indicates a place where the road has a big hole due to a melting ice lens.

5.2.2 Tyre Pressure Management (CTI / TPC technique)

A relatively new and very promising technology to tackle spring thaw weakening is the use of road friendly "central tyre inflation", or "tyre pressure control", techniques (CTI or TPC) to reduce the tyre pressures of heavy trucks when driving on weak roads and/or when using lower speeds. This technology and its potential saving will be summarized in more detail in chapter 6 of this report but its advantages in the management of spring thaw weakening management are presented in the following.

According to ROADEX the use of CTI has a great potential in mitigating the effects of spring thaw weakening, on both gravel and paved roads. The CTI footprint acts as a "snow shoe" and spreads the truck load on a longer area, thus reducing the effective stresses and risk for deformations in the road structures (Figure 522_1). If all heavy vehicles driving on low traffic volume road could be equipped with a CTI/TPC system, road owners could abandon most of their load restrictions, and on those roads where restrictions were still needed, the time for the restrictions could be much shorter. CTI is especially good effective in dealing with weakening after heavy rains in the fall and after mid-winter freeze-thaw cycles that can cause major problems both to roads and transportation projects. Currently CTI is used in ROADEX countries mainly in timber trucks, but this technology should be used in all the heavy vehicles using low volume roads, such as road maintenance vehicles, dairy trucks, school buses etc.

The CTI will not however solve all of the problems related to seasonal changes. Roads in the beginning of the spring thaw period can be so weak that even CTI cannot help, apart from making the road surface material less plastic. The research results in USA have shown that the best benefits can be gained with CTI trucks when load restrictions can be applied on the road during the first 2-3 weeks after winter when the road surface starts to thaw. At that time a dry crust, even a weak one, can form in the road surface and that layer can cope with the stresses caused by a CTI vehicle. If this policy can be used, damages could be reduced by 80-90%.

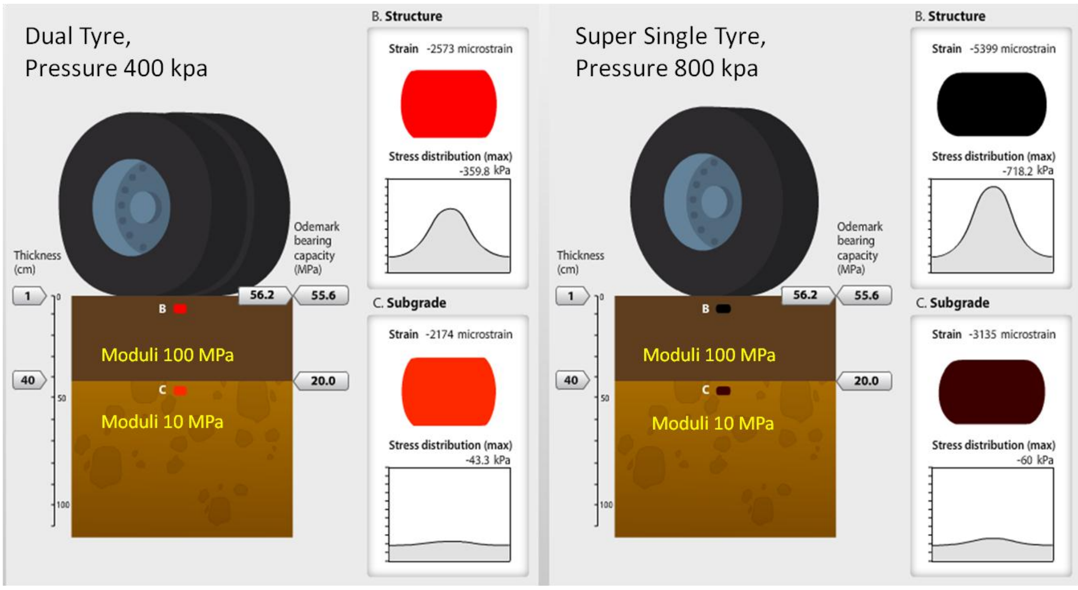

Figure 522_1. Benefits of tyre type and tyre pressure on the level of stresses and strains in a road structure and subgrade soil in a gravel road during a spring thaw weakening. The left case presents dual tyres with CTI with a tyre pressure of 400 KPa, and the right case presents a super single tyre with full tyre pressure of 800 KPa. The black colour in the "strain" field indicates a high risk for immediate failure under the truck load.

5.2.3 Problem Diagnostics and Precise Strengthening

It has been said many times that road diagnostics and rehabilitation design is too expensive when there is a limited amount of funding available for roads, and especially for low traffic volume public roads, private roads and forest roads. ROADEX research however has shown that for roads with thin and weak structures, it is extremely profitable to do a good design based on road diagnostics (see chapter 3 in this report). Investments are highly profitable when strengthening is only made on the weakest sections, and stronger road structures are not strengthened for "security´s sake"

A good example of major potential saving is the repair of spring thaw weakening sections in Finland. According to Perälä et al. (2011), the costs for the standard spring thaw weakening rehabilitation structures in Finland (200 mm base course + 100 mm wearing course) have varied from 20,000 €/km up to 120,000 €/km. A budget figure for the detailed diagnostics and design with gravel roads using techniques recommended by ROADEX varies between 400 – 1200 €/km, i.e. only 1- 4 % of the total costs. This means that, for instance, all of the design costs could be paid back by just 4-10 m/km better positioning of the strengthening structures. Furthermore, as shown earlier in the “drainage” chapter, on many occasions spring thaw weakening problems could be treated merely by improving the road drainage.

The reports and eLearning packages published by ROADEX project provide information on the design principles and different structural solutions for each type of problem related to seasonal changes and differing severities.

5.2.4 Monitoring of Seasonal Changes and Heavy Traffic Management

The severity of spring thaw weakenings in rural roads can have great variations across the years and it is not always economically possible to design a road structure to carry heavy loads on the weakest days of a bad spring thaw period that takes place once in ten or twenty years. That is why it is extremely useful to have a monitoring system that can provide reliable information on the frost and moisture content in road structures and subgrade soils before the freezing period and during frost thawing. Such monitoring information can be highly helpful when making decisions on possible load restrictions on weak roads. Also, as stated earlier, the greatest benefits of CTI trucks can be achieved if, based on the seasonal change monitoring results, road closures can be made on the weakest roads until a dry crust has been formed in the road surface.

The economic benefits of this kind of monitoring system is difficult to evaluate but a good idea of likely figures on the potential economic impact of a severe winter taking place once in 20 years to the roads are given by Ray et al. 1993 (see also Isotalo 1993 and C-SHRP 2000). Table 524_1 gives some examples of this evaluation for countries slightly warmer than the ROADEX countries. Even though the figures would be somewhat lower in Northern Europe the benefits of a good monitoring and warning system are clearly evident.

Table 524_1. Cost savings attributed to load restrictions in eastern and Central Europe (modified after Ray et al. 1992). The calculations are based on the occurrence of a severe winter once in every 20 years.

Country	Road network sensitive to freeze-thaw (%)	Cost of severe winter with load restrictions (mill USD)	Cost of severe winter without load restrictions (mill USD)	Associated cost saving (%)
Hungary	40	300	3100	90
Poland	15	400	1800	75
Romania	50	600	4400	86
France (1985)	20	4900	8000	40

A range of types of monitoring systems for seasonal changes and spring thaw weakening monitoring are presented in ROADEX reports.

6. ROAD FRIENDLY VEHICLES

As mentioned in Chapter 5, a very promising technology for permitting heavy haulage vehicles to use weak roads is the use of road friendly “Central Tyre Inflation” (CTI) systems, also known as Tyre Pressure Control” (TPC). This system permits the driver of the vehicle to reduce the tyre pressures in the wheels of the vehicle whilst the vehicle is in motion to suit its speed, the load being carried, and the condition of the road (figure 5_1). Reducing the tyre pressure not only increases the tyre’s contact length on the road, it also reduces the shear stress applied by the tyre to the road surface. Research carried out in the ROADEX IV project has shown that lowering the tyre pressure can improve its traction on weak and poor road surfaces, and this can be a real benefit to both road owners and truck operators dealing with low volume roads and gravel roads.

ROADEX has been a pioneer in the use of CTI systems on timber haulage vehicles across the Northern Periphery. These did not exist in Scotland or Finland before being piloted in the Scottish Highlands in the ROADEX III project in 2006 although some were being trialled in Sweden. Since 2006 however the numbers of trucks equipped with CTI have grown annually in Scotland (> 100) and Sweden (> 120) in response to changing economic and environmental conditions, and as a result of ROADEX involvement Finland has also started to introduce CTI on a limited number of timber trucks. Timber haulage companies in particular are seeing the business benefits and opportunities that can arise in having CTI systems fitted. This is particularly the case on weak public rural roads where public road organisations and forest agencies are coming under increasing pressure to permit timber haulage operations along weak public roads to support local communities and industries.

This section of the report will consider the benefits and savings of using CTI under the three headings of a) road owner, b) truck owner and c) driver health.

Figure 6_1. CTI double tyre with full 800 KPa tyre pressure (left) and with reduced 400 KPa tyre pressure.

a) Road owner benefits

The main benefit of CTI to the road owner lies in its potential to reduce the levels of damage caused by heavy traffic on vulnerable sections of the road network all year round, and to mitigate the effects of spring thaw weakening on affected gravel and paved roads. ROADEX has shown that lower tyre pressures can lower the stresses and strains in unbound roads and thin pavements, and CTI can now be considered as an option for lifeline routes in place of weight restrictions. The greatest benefits of the CTI is on protecting the pavement and unbound base in the top part of the pavement structure during the spring thaw period when the top part of the road has thawed and is saturated with water whilst deeper in the road structure and subgrade soil is frozen (figure 5_2).

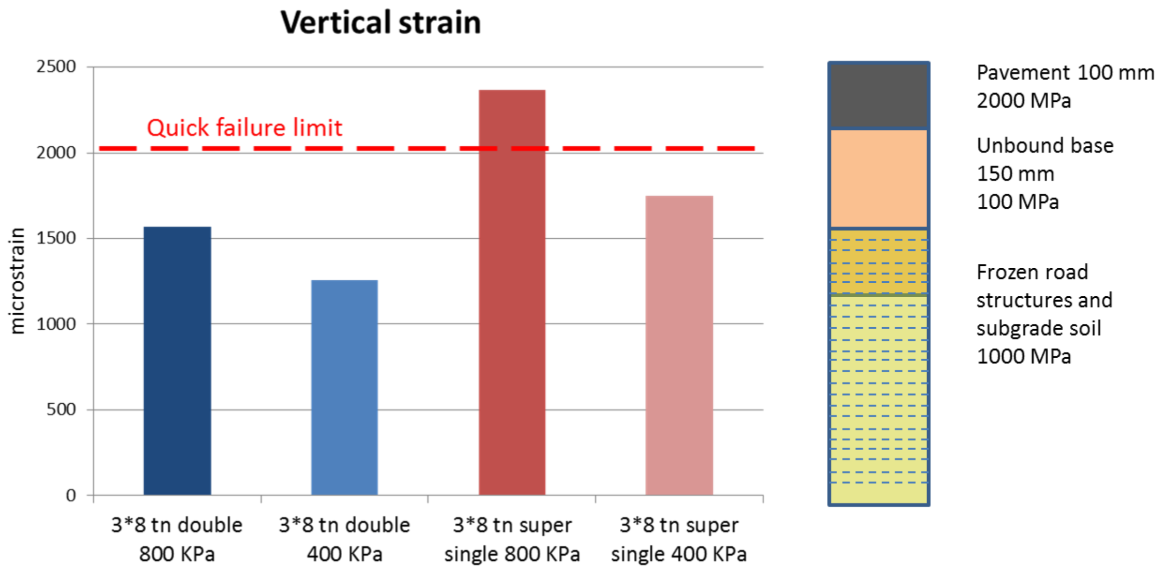

Figure 6_2. Example of the effect of CTI on maximum vertical stress on a paved road after a freezing season for a 3* 8 tonne triple bogey axle configuration.

The use of CTI equipped vehicles can also be an alternative option to temporary or seasonal load restrictions on roads where the restriction is only required during the period the road is weak. The use of CTI in this scenario can prolong the lifetime of the road by minimising the stresses and strains it is subjected to during the weak period. A good example for encouraging haulage companies to use the CTI technique comes from Sweden where load restrictions do not apply with CTI trucks (Figure 6_3).

Figure 6_3 Temporary road sign on Road No S926 in Värmland, Sweden (The lower plate of the sign says "Does not apply to the CTI project")

b) <u>Truck owner benefits</u>

CTI can offer a number of benefits to truck owners and these commercial reasons are the real driving forces for the adoption of CTI in the timber haulage fleets of the Northern Periphery. In summary these are:

- A more "road friendly" vehicle for road owners
- Greater confidence in CTI vehicles being able to enter forest roads without getting stuck

- CTI vehicles accessing locations not possible before
- Reduced number of drive axles on CTI vehicles (in Scotland) resulting in a higher payload
- Increased lengths of hauling seasons
- Improved tyre management, less wheel spin, extended tyre life
- Improved vehicle ride, fewer mechanical breakdowns, longer working life
- Increased revenue per vehicle

c) Driver health benefits

The reactions of drivers to CTI have generally been positive, with reports of a smoother vehicle ride and improved comfort in the cab. The drivers questioned by ROADEX felt that the improved traction, lesser wheel spin, fewer tyre changes and reduced vehicle recovery incidents were positive contributions to improved health and safety. Accidents were more likely to happen in timber operations when the driver was out of the safety of the cab and CTI was seen to have a positive benefit in reducing the need for the driver to dismount from the vehicle.

Regarding vehicle vibration and driver health the ROADEX IV project reported that CTI was very efficient in isolating “shake” vibration from short wave road roughness (megatexture < 0.5 m) such as potholes and corrugated ice surfaces. It has not been possible to calculate the benefit to driver health in strictly monetary terms but anecdotal evidence is increasingly indicating that driver health is better when using ‘road friendly’ vehicles equipped with CTI. This could be the greatest benefit of all.

7. QUALITY CONTROL / QUALITY ASSURANCE

Over the last twenty years governments across the Northern Periphery areas have been reorganizing their public road administrations so that now almost all “production” works and tasks are normally outsourced to private contractors and consultants. This means that practically all projects and contracts related to road condition management are now done through a procurement process, and contractors with the cheapest bids usually do the work. Because of this, contractors adhere to the contract documents and do only the minimum works specified in them. This fact has caused major pressures in the road owner procurement organizations to prepare “waterproof” bidding and contract documents to ensure fair competition. This, regrettably, has also led to procurement departments being very reluctant to make changes to established contract documents and as a result new ideas and technologies have become increasingly difficult to be accepted and implemented, even though they could save significant sums of money.

A further issue that has not been raised in public discussion so far is the effectiveness of quality control and quality assurance of contracts. Contracts are subject to fierce price competition and increasingly, once contracts have been awarded, incentive systems in many companies are being based on how much extra savings the project can achieve, compared to the price submitted in the contract documents. These “savings” unfortunately can be made quite easily by building the structures thinner than they were designed – or ignoring the maintenance operations needed.

To demonstrate the levels of potential “savings” to a contractor the ROADEX project considered a number of scenarios using real construction prices. The following example describes a 2 km long road section with a design of:

- milling away 50 mm of old pavement
- soil replacements to three worst sections 3*200 m, depth 1.8 m
- new unbound base 200 mm, length 2 km
- bound base 50 mm and bound wearing course 50 mm, length 2 km

The estimated total cost for this project was 338,000 €.

Table7_1 shows the potential “savings” if road structures were made thinner and if the soil replacement sections were made shorter. The table shows that building the bound layers thinner than designed is especially profitable.

Table 7_1. Potential elements for contractor savings if the pavement structure is constructed thinner, or shorter (soil replacement), than designed.

	Total costs [€]	Savings [€]	Savings [%]
Planned structure	337976	0	0 %
Soil replacement 1,6m	327212	10764	3 %
Soil replacement 1,4m	317444	20532	6 %
Soil replacement 1m	304136	33840	10 %
Soil replacement 180m	331228	6748	2 %
Soil replacement 160m	324481	13495	4 %
Base course 180mm	330896	7080	2 %
Base course 150mm	318851	19125	6 %
Pavement 90mm	318336	19640	6 %
Pavement 80mm	298836	39140	12 %
Pavement 60mm	259836	78140	23 %

When the results of the calculations in Table 6_1 are put together into different "risk scenarios" the following conclusions can be made:

1. No risk scenario.
   In this case all of the road structures are constructed 10 % thinner than designed, i.e. 90 mm of bound layers, 180 mm of unbound base layers, and soil replacements to a depth of 1.6 m. The potential savings in this case are 37,500 €, which equates to 11 % of the total contract sum. The structures constructed are so marginally thinner than the design that they are unlikely to be detected, and there is little risk for any actions from the road owner´s side.

2. Low risk scenario
   In this case all of the road structures are constructed roughly 20 % thinner than design, i.e. 80 mm of bound layers, 150 mm of unbound base layers, and soil replacements to a depth of 1.4 m. The potential saving in this case are 78,700 €, which equates to 23 % of the total contract sum. In this case some of the thin structures could be detected, but the penalties in practice have usually been relatively very small or nothing. In most cases no problems will appear during the short guarantee period (5 years).

3. High risk scenario
   In this case all of the road structures are constructed roughly 20-40 % thinner than design, meaning 60 mm of bound layers, 150 mm of unbound base layers, and soil replacements to a depth of 1.0 m. The potential savings are now 131,000 €, which equates to 39 % of the total contract sum. In this case there are high risks of the road owner making claims against the contractor and some penalties might have to be paid. The constructed road might also have damages appear within the guarantee time.

The example described above is of a small 2 km long project and normally rehabilitation projects are of the order of 6-10 km, which makes any "cheating" even more rewarding if attempted. The only action against this type of practice is stricter quality control quality assurance audits, and the measurement of the constructed thicknesses of road structures relative to the design on completion of the works by the road owner.

Stricter quality control using new technologies will be able to confirm that all road structures have been built with the specified design thicknesses, proper compaction and material quality. This can be a beneficial measure in the long term for the construction industry as it would stop the discussions about the "grey" area between contractors. Additionally, the "fear factor" would mean that everyone will know that if they cheat they will get caught. A further benefit will be that contractors with high professional ethics, constructing high quality products, will become competitive again in road construction and rehabilitation projects. Construction projects that everyone can be proud of will also increase the attraction of road engineering as a career for young people.

Detailed quality control and quality assurance using new technologies will not only prevent cheating in the industry but will also offer opportunities for learning experiences. Many times failures happen during the construction project, and contractors are not even aware of them. Good quality control survey systems will enable contractors to learn from their mistakes, and consequently improve their work practices.

8. CONCLUSIONS AND RECOMMENDATIONS

The title on the cover of this report "*ROADEX benefits and savings - achieving more with less*" was chosen with the aim of offering hope to the ROADEX Partners that reasonable low volume road network condition can still be assured even though resources have been decreasing.

The portfolio of problems experienced on the Partner low volume road networks is extensive and there is not one single issue or task by means of which all of the problems will be solved. The ROADEX recommended "toolbox" for efficient road condition management comprises four main tools: a) better maintenance practices, b) focused rehabilitation design, c) monitoring of road condition and seasonal change, and d) the use of road friendly vehicles. These however will require all parties to be willing to change their practices. This includes not only road owners and road design, construction and maintenance crews, but also industries using heavy transports on the networks, trucking companies, and political decision makers. A real win-win case can be achieved with even greater efficiency, (up to 50 %), if and when all parties can co-operate to find optimal sustainable solutions to keep the condition of the road network in a good and safe condition.

A summary of the best practices proposed by ROADEX is presented in the following:

<u>Drainage is the weakest link:</u>

The first and most cost-effective task to improve efficiency in road condition management, and save money on annual paving costs, and spring thaw management in gravel roads, is better drainage management. ROADEX field tests have shown that poor drainage is a major problem in Ireland, Scotland, Norway, Sweden and Finland, with only Iceland having adequate road drainage in general.

Potential savings on paved roads can vary from 10-40 % of the annual paving costs if the drainage is kept in good condition. Calculations have shown that the thinner the pavement, the greater are the savings in keeping the road drainage in perfect shape. For instance, potential savings with an 80 mm pavement thickness can be 2000 €/year/km, and for a 120 mm pavement thickness the savings can be 600 €/year/km. (Pavement thicknesses in low volume roads in the Nordic countries are normally even thinner than 80 mm). In practice this means that potential savings of tens of millions of euros can be achieved in each ROADEX partner country if road drainage can be improved, and kept in good condition. This is likely to require significant changes in maintenance practices at the start, but there will be real payback over time.

ROADEX has published new solutions on how to improve drainage in road sections where normal ditch cleaning is insufficient, and identified a number of special cases that have great influences on road performance. For example, the new ROADEX survey techniques have shown that poorly performing drainage under private access roads can cause major damage to the adjacent main road. This is a particular problem in Finland where the maintenance contractor is not responsible for private access road culvert maintenance.

These new drainage management practices may require changes in existing procurement policies and maintenance follow-up practices. The existing visual inspection methods will not be enough. The new laser scanner techniques described by ROADEX provide fast, cheap and objective solutions that can be used to ensure that road drainage is always kept in good condition.

<u>Diagnostics based and focused road strengthening</u>

The second step in improving the efficiency of road condition management is to make road strengthening more cost effective. For this ROADEX recommends that all road strengthening and rehabilitation solutions should be based on objective road survey data and not just on an "expert opinion" made through a vehicle windshield, or based on data from a PMS database with data averaged to 100 m. The key issue at this stage is to identify the underlying reasons for the damages being seen rather than just fixing the symptoms, a practice that has been all too common during former years. Additionally the proposed strengthening structures should be designed based on survey data to meet a target bearing capacity. This will prevent expensive over-dimensioning.

Using modern road diagnostics and design techniques in road strengthening projects can result in high savings (10-60 %) in project costs and long term road condition management costs. Better and more precise GPS positioning techniques can give savings of 5-20 %. When road strengthening can be optimized using road diagnostics to meet a target level the savings can be 15-50 % of the project level costs, and the saving over the lifetime of the rehabilitation can be up to 50 %. The ROADEX project has shown that strengthening of a road network with limited resources should be started by strengthening the poorest sections first. In these cases designs based on lifetime cost calculations can provide 10 % to 80 % cheaper solutions, with investments spread over 20 years. The challenge in this policy is that contractors will need to change their practices from using single structures throughout, to using a number of precisely targeted structures. This is likely to increase individual prices per square metre, but will result in substantial reductions in overall costs in the long term.

ROADEX has also carried out research and published new information for a number of special engineering problems associated with low volume roads in the Northern Periphery. One special topic, shared by all ROADEX partners, are roads built and resting on peat, where many kinds of geotechnical issues give problems to road performance. ROADEX reports on best practices, and field test reports from different countries, offer guidance on how to carry out sustainable strengthening design. The key words in these cases are “where, how severe and risk management”. Savings can be seen in long term management costs.

Finally the ROADEX project has provided new information how to design road widening in a way that prevents later problems, such as reflection cracking that increases maintenance costs over the lifetime of the road. The ROADEX report on road widening provides guidelines on how to repair road widening problems.

Road friendly vehicles

An important issue in sustainable road condition management that road engineers cannot manage by themselves, and need strong political support and legislation, is the use of road friendly vehicles. ROADEX laboratory tests, theoretical modeling and experiences from the field show that heavy trucks with high pressure super single tyres, designed for European motorways, are destroying low volume roads across the Northern Periphery. At the same time new road friendly trucks with dual tyres and tyre pressure control systems have entered to the market. The ability of CTI/TPC trucks to increase the “footprint” of their tyres, and reduce stresses in the pavement and base course, is good news for weak low volume public and forest road structures. If all the heavy vehicles using low volume roads were equipped with tyre pressure controls systems, permanent deformation problems and road damages could be reduced by 40-80 %.

Such changes in the use of heavy vehicles will need changes in legislation, and decisions will have to be made on who will pay the costs. But the payback time will be very short. For instance, equipping all Finnish timber trucks with CTI/TPC systems would cost roughly 40 million €, at a time when the costs for spring thaw weakening, solely to the Finnish forest industry, has been calculated to be roughly 100 million €/year.

Despite ROADEX showing that heavy trucks can have a detrimental effect on low volume roads, the project can also support increasing the total weights of heavy trucks on routes where the existing bridges allow it. ROADEX tests in Pajala in Sweden showed that increasing the total loads of trucks was a sustainable solution to the road haulage of mining ore, as the heavier loads reduced transportation costs, reduced carbon emissions, and when equipped with road friendly tyre configuration were even better at reducing the stresses caused to the road pavement. The only negative effect on road structures were those road sections located on very weak subgrade soils and these are to be strengthened before haulage starts.

In addition to the fact that CTI/TPC trucks are friendly to roads, they are also ‘friendly’ to trucks and to truck drivers. ROADEX tests on human body vibrations have shown that lower tyre pressures can reduce the level of unhealthy vibrations causing heart and cardiovascular problems.

Monitoring road condition and managing seasonal changes

Roads do not get damaged at an even rate under seasonal changes, freeze-thaw cycles, frost action and permanent deformation, and more than 80 % of road distress appears during winter and springtime. For this reason it is economically wise to make sure that low volume public roads and forest roads are built to cope with a severe spring thaw that takes place every 20 years. Road owners should also have policies for the effective management of seasonal change for the same reason.

The basic elements of a good spring thaw weakening management policy are the practices mentioned above, i.e. good drainage maintenance, focused road strengthening and the use of road friendly vehicles. In addition to this road owners should also have a monitoring system to protect the roads by load restriction, or even road closures in the case of an extremely bad spring thaw weakening period, or after repeated bad freeze-thaw cycles. ROADEX has published several reports on spring thaw weakening management and has shown that good road performance can be ensured throughout the year with appropriate practices.

It is difficult to estimate the potential savings of seasonal change monitoring and decision making systems as severe conditions may only take place once in 20 years. The World Bank has reported that savings of 40-90 % are possible, but this figure might be slightly high for Northern Europe because road structures are thicker. On the other hand almost all roads in the Northern Periphery are exposed to seasonal changes and it is generally accepted that numbers of severe freeze-thaw cycles are likely to increase over the coming years as a result of climate change.

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ROADEX PROJECT REPORTS (1998–2012)

This report is one of a suite of reports and case studies on the management of low volume roads produced by the ROADEX project over the period 1998-2012. These reports cover a wide range of topics as below.

- Climate change adaptation
- Cost savings and benefits accruing to ROADEX technologies
- Dealing with bearing capacity problems on low volume roads constructed on peat
- Design and repair of roads suffering from spring thaw weakening
- Drainage guidelines
- Environmental guidelines & checklist
- Forest road policies
- Generation of 'snow smoke' behind heavy vehicles
- Health issues raised by poorly maintained road networks
- Managing drainage on low volume roads
- Managing peat related problems on low volume roads
- Managing permanent deformation in low volume roads
- Managing spring thaw weakening on low volume roads
- Monitoring low volume roads
- New survey techniques in drainage evaluation
- Permanent deformation, from theory to practice
- Risk analyses on low volume roads
- Road condition management of low volume roads
- Road friendly vehicles & tyre pressure control
- Road widening guidelines
- Socio-economic impacts of road conditions on low volume roads
- Structural innovations for low volume roads
- Treatment of moisture susceptible materials
- Tyre pressure control on timber haulage vehicles
- Understanding low volume pavement response to heavy traffic loading
- User perspectives on the road service level in ROADEX areas
- Vehicle and human vibration due to road condition
- Winter maintenance practice in the Northern Periphery

All of these reports, and others, are available for download free of charge from the ROADEX website at www.ROADEX.org.