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Co-operation level: Common Obligation

P2R2C2

Start date of project: 01/02/09
End date of project: 31/07/10

Duration: 18 Months

Monitoring Progress Report 01

Reporting period from 01/02/09 to 30/09/2009

This report is prepared by the Contractor of the research project and presented to the Programme Executive Board.

ENR SRO3 Programme Executive Board:

AT,	Federal Ministry of Trannsport, Innovation and Technology (BMVIT)
DE,	Federal Ministry of Transport, Building and Urban Affairs (BMVBS)
DK,	Ministry of Transport, Danish Road Directorate (DRD)
ES,	Centre for Studies and Research in Public Works (CEDEX)
FI,	Finnish Road Administration (Finnra)
IE,	National Roads Authority (NRA)
NL,	Directorate of Public Works and Water Management (RWS)
NO,	Norwegian Public Roads Administration (NPRA)
PL,	General Directorate of National Roads and Motorways (GDDKiA)
SE,	Swedish Road Administration (SRA)
UK,	Department for Transport, Highways Agency (HA)

Programme Leader:
SE, SRA

Programme Executive Chair:
AT, BMVIT

Contractor:

U.K.	University of Nottingham	(Coordinator)
Slovenia	ZAG	
Finland	VTT	
Norway	SINTEF	

Objectives
Describe the objectives of the project stated in the MoU and any modifications introduced later (not more than ½ page):
The project's main aim is to give a general overview of the consequences that future climate change will probably have on the highways and the possible countermeasures. Because the countries involved represent a large part of Europe, the project does not want to address the attention to local realities, but rather investigate the main climatic changes that are likely to occur in the continent and how they relate with roads from a performance point of view. Thus, the study will involve literature review of the relationships between temperature and water changes with the whole road structure; laboratory tests and models will cover those areas that are not completely exhaustive from the literature review.

Technical Description
Describe the items of technical work, the mode of operation, possible subdivision in Working Groups and how management is organised (no more than 2 pages):
■ WP 1 Climate (VTT) Collect and interpret and possibly refine the available predictions for national and local purposes. Draw on existing publications. Identify the changes in mechanical material response that can be expected of asphaltic materials (including porous asphalt), unbound and stabilised materials and of subgrade soils as a consequence of these climatic changes. ■ WP 2 Materials (UNott) Identify the effects of water in the road pavement. Perform laboratory tests, especially water sensitivity and freeze-thaw, on asphalt, porous asphalt and lower pavement materials where known data insufficient. Reformulate materials for improved performance. Evaluate methods to enhance resistance to water and to freeze-thaw cycles. Perform tests to demonstrate improvements and enhancement methods. ■ WP 3 Pavement structure (SINTEF) Perform analyses of a range of pavement types, on a range of subgrades in a range of climates with existing and reformulated material properties to determine the effects of climate change on functional properties like rutting and fatigue. ■ WP 4 Pavement hydraulogy (UNott) Perform simulation analyses of a range of pavement types, on a range of subgrades in a range of climates with existing and reformulated material properties to determine the effects of climate change on the hydraulic properties like the ability to wet, drain and hold water. Investigate alternative drainage regimes and perform heat flow calculations for estimation of freezing front position and duration. ■ WP 5 Advice and dissemination (ZAG) Identify future rehabilitation and routine maintenance regimes that can be anticipated as being necessary to economically support the pavement's asset value as climate changes. Perform cost-benefit analyses on reformulated materials and novel usage. Formulate advice into a useable tool and prepare web version. Produce brochure, deliver workshop and lectures. Publish reports. Circulate users.

Participation and coordination
Project Steering Group (PSG) Geoff Richards, Highways Agency, Temple Bar, Bristol, UK Rudi Bull-Wasser, BASt, Bergisch Gladbach, Germany Gert Åhe, Danish Road Directorate, Copenhagen, Denmark **Meetings of the PSG:** 17-18th September 2009 Nottingham, UK 23rd September 2009 Nottingham, UK
Meetings of the Contractors: 9th February 2009, Espoo, Finland 17-18th September 2009 Nottingham, UK …

Report on Results (so far)

<table>
<tr><th>Milestone, date: W.P. 1.1, 30/09/09</th><th>Assessment by PSG</th></tr>
<tr><td>The aim of this working package, developed by VTT, was to collect and interpret and possibly refine the available predictions of climate change on a European scale. This working package is finished, and maps of the future predictions regarding those climatic inputs that are likely to affect the roads the most have been created. However, Lasse Makkonen and Jouko Törnqvist (who developed the maps) offered their availability in case new information is found to be needed in the future.</td><td rowspan="3">RED
AMBER
GREEN</td></tr>
<tr><td>Results:</td></tr>
<tr><td>Climate change projection maps have been presented for those climate variables that were considered most likely to affect the long-term performance of road networks in Europe. These projections are based on climate simulations by a regional climate model and using certain likely future emission scenarios. The maps of the simulated changes were produced by at the Department of Physics / Meteorology of the University of Helsinki.

Data from two global climate simulation models, the Hadley Centre HadAM3H and Max-Planck Institute ECHAM4/OPYC3, were used to drive the numerical regional climate model RCAO. HadAM3H is a high resolution (1.875° longitude x 1.25° latitude) atmosphere model for which the sea surface temperature and sea ice conditions were derived from observations and earlier lower-resolution coupled atmosphere-ocean simulations. ECHAM4/OPYC3 is a coupled atmosphere-ocean model with a resolution equivalent to a grid spacing of 2.8° longitude x 2.8° latitude.

For driving the regional climate model, 30-year periods from both the HadAM3H and MPI/ECHAM4/OPYC3 simulations, the "control run" (September 1960 to December 1990) and the "scenario run" (September 2070 to December 2100) were used. The 30-year annual global mean warming predicted by HadAM3H from 1961 - 1990 to 2071 - 2100 is 3.2 °C in scenario A2 and 2.3 °C in scenario B2. The corresponding warming predicted by ECHAM4/OPYC3 is 3.4 °C for A2 and 2.6 °C for B2. Taking into account a wider range of emission scenarios and model-specific climate sensitivities, they computed a global warming of 1.5 - 5 °C from 1975 to 2085.

The Rossby Centre coupled regional climate model RCAO consists of the atmospheric model RCA2 and the Baltic Sea model RCO. RCA2 was run in a rotated longitude-latitude grid with a 0.44° (approximately 49 km) resolution in both horizontal directions and with 24 levels in the vertical. The integration domain of RCAO covers an area of 106 × 102 grid squares. The Baltic Sea model RCO was run with the horizontal resolution of 11 km and with 41 levels in the vertical.

Four climate projections were obtained: two emission scenarios A2 and B2, and both of them as simulated based on boundary conditions from two global climate models Had and MPI.</td></tr>
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<table>
<tr><th>Milestone, date: W.P. 1.2, 30/09/09</th><th>Assessment by PSG</th></tr>
<tr><td>Work package 1.2, developed mainly by the University of Nottingham, is centred on the literature review of the likely effects on climate change on current roads; this includes general studies of how the road performance is related to climate, and also studies focused on what has to be expected by the future climate changes predicted. This work package has concluded and a report (Report Nr 1) is the output.</td><td rowspan="3">RED
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<tr><td>Results:</td></tr>
<tr><td>Here are the main conclusions that could be drawn by the literature review study.

The most likely climate changes to be expected in the future on a global scale have been investigated by the Intergovernmental Panel on Climate Change (IPCC) project and are listed in the AR4 report produced. Such climate predictions are based on the changes in CO_2 concentration in the atmosphere that will be likely to be observed if different economic, industrial and ecological behaviours will be followed. A range of possible scenarios has been developed based on many climate models. From the IPCC's AR4, some general conclusions, independent on the geographical zone and on the scenario chosen, can be drawn. An increase in temperature is expected everywhere (especially extreme temperatures), which will consequently cause a melting of terrestrial ice and thus an increase in sea levels. Spring thawing in cold regions is likely to occur earlier. Also storms and surges are likely to be more frequent in the future decades, while the amount of precipitations seems to increase in Europe, at least during winter. Some further, consequential issues of relevance to roads are increasing coastal erosion and the relocation of population due to climate change. Other studies have been performed on a local scale. In particular, the UKCP09, for the UK, and Regclim, aimed at producing scenarios for climate change in Northern Europe, have been reviewed. The former is of particular importance as it introduces the concept of "probability of occurrence" for the different scenarios.

Temperature, solar radiation, rainfall and groundwater level rise are the climate change-related issues that will most affect roads. The predicted rise in temperature and in solar radiation, can cause rutting and ageing of the asphalt, with consequent development of cracking. In cold areas, thawing can become a more significant issue if the temperature floats daily around 0˚C during winter, as daily or multi-daily thawing can take place, with consequent temporary loss of strength on the road and need of traffic limitation. An increase in rainfall will lead to asphalt ravelling problems, and even cracking formation. When rainfall water reaches the unbound subgrade, destabilisation can take place if the drainage system is not able to remove it quickly. Drainage can be blocked by high intensity rainfalls, and the presence of cracks in the asphalt will represent a means for water to reach the subgrade even if the asphalt is almost impermeable. The increase of sea level and the probable increase of rainfall might change the groundwater level, and if this is too shallow, it can reduce the strength of the soil underneath the road. Some performance improvements can also result from climate change; the rainfall increase is likely to be concentrated</td></tr>
</table>

in winter, while summers will not probably undergo large differences from the present, but the rise in temperature will increase the evaporation in thin asphalt layer roads, resulting in a drier subgrade; as a consequence, the road will gain strength. The effects of water and temperature changes are inter-related and thus cannot be considered separately. Some experimental studies regarding the consequences of climatic factors on the road properties have been performed in the past, but the results are not always in agreement and, the few equations that try to describe them, can usually be applied only on a local scale or on particular materials. However, some general aspects have been found. The temperature of the asphalt follows the same daily and seasonal changes of the solar radiation, although such temperature variation is less and less marked with depth. Air temperature is less important than solar radiation. The temperature of the road surface is always higher than that of the air. Some simple equations that link air temperature with asphalt temperature do exist; although they do not take into account all the factors, they can be valuable for our purposes. The relationship between rainfall and subgrade moisture content is, instead, much less clear. The rainfall amount does influence the moisture content, but the extent is very variable. This is because soil, road surface, drainage and surrounding conditions can heavily affect the response of the road to rainfall. Thawing problems seem to be more related to temperature than rainfall, and can occur on a daily basis. However, rainfall prior to freezing (e.g. in the Autumn) has a large influence, as well. It is generally recognised that moisture content related problems and, in cold regions, thawing problems, are the main cause of pavement failure. Also the effect of the change in groundwater level is not very clear and will need further studies (probably in W.P. 4.1). Projects involving an assessment of the climate change impact on roads and the development of plans to address the possible problems that will arise have been performed, on a national scale, by New Zealand (Transit) and Australia (Austroads). Transit identified the most vulnerable assets and analysed them in terms of necessity of acting in the present to manage future potential related problems, and in terms of feasibility. The results showed that the best solution was to repair the asset at a time when the need becomes evident, as current asset management practice seems to be adequate to cope with most predicted climate change impacts. Austroads' analysis of climate change impact stresses the importance of population and settlement patterns and the change in road transport demand. The output shows that no immediate action is needed, although higher maintenance costs should be expected while future road reconstruction designs might need changes to overcome climate-related problems. Models capable of describing the road performance with changes in temperature, rainfall etc. need to be used for our purposes; literature can be found about existing solutions. To take into account costs-related issues, PLCC and HDM-4 have been used by Austroads. MEPDG seems to be an interesting tool to study the sensitivity of pavement performance to climate change, and it is currently used in Canada and, recently, also in Norway. The implications of the study are that a more detailed description of how climate is likely to change in the part of Europe of the project's interest is needed. The predictions should be on a short and medium term, as the road life expectancy is usually less than 50 years; thus, long-term	

predictions are not needed, except insofar that design standards will need altering. To assess the road performance for a variation in temperature, solar radiation, rainfall and groundwater level, models based on experimental field data are needed. Some information was found regarding the relationship between air temperature and road temperature, and therefore these existing relationships only need to be validated, or slightly modified, applying the existing equations to experimental data collected from the literature. Once the relationship between climate and asphalt temperature is known, the properties of asphalt related to its temperature are well known and documented in the literature. The effects of climate on subgrade moisture content are instead much less clear due to the greater number of dependent variables. This subject will therefore need more investigation; this will be concentrated on water infiltration, mitigation and pavement deterioration by means of modelling and laboratory tests to be done in the next working packages. The change in soil strength related to moisture content changes will be finally studied, to have a complete description of a road's performance with climate change. The cost-related analyses of the future interventions carried out by Transit New Zealand and Austroads seem to be a very important starting point for W.P. 5. In particular, an analysis of the population migration, age, demographics and immigration are likely to be a major issue that must be taken into consideration. Both the Transit and Austroads projects deduced that it is not economical nor sensible to look at short-term changes and thus start to modify the maintenance methods from now, because the uncertainty is too high; rather, road design methods should be changed in order to introduce climate changes in the design models in order to overcome the possibility of climate change-related lower performance of current road designs. This means that, in the P2R2C2 research study, we might decide not to consider maintenance problems related to short-term climate changes, but rather to concentrate on the development of new road design methods that take into account climatic issues and on the study of suitable materials.	

Milestone, date: W.P. 2.1, 30/09/09	**Assessment by PSG**
Task 2.1 involved a literature review to define knowledge on links between water and pavement performance. This has been concluded and the output is Report Nr 2. This working Package has been developed mainly by the University of Nottingham.	**RED** **AMBER** **GREEN**
Results:	
From the literature, important information could be retrieved. First of all, the importance of the presence of water was clear: about 80% of road distresses and pavement damages are related to the presence of excess water, water that affects the behaviour of all layers – bound asphaltic material layers, granular layers and subgrades. The expected life of a road can be influenced significantly by the subgrade's resilient modulus, and this can be strongly affected by the presence of water. The soil is usually in a partially saturated condition, and suction contributes to the soil's strength. If the water content increases, the	

suction decreases until it disappears, and, in saturated conditions, the soil can experience a large loss of strength. To avoid accumulation of water below the pavement, the lower layers of the pavement must be permeable and connect to a drainage system, so that any water that infiltrates from the surface and from the lateral shoulder slopes and verges can exit as quickly as possible. The drainage system should also assist water from exiting the subgrade, although its ability to do this will be limited by the permeability of the subgrade soil.

Water can pass through the asphalt layer and reach the subbase in two ways: through the voids present in the asphalt, and through the cracks and joints. Water that passes through the air voids depends on the permeability of the pavement, and thus it is related to the grading curve of the aggregate used, to its compaction level and to the proportion of bitumen used (high volumes will fill voids better). Unless it is porous asphalt, asphalt is usually considered almost impermeable, whereas porous asphalt is characterised by a very high air void volume (about 20%), and designed with the purpose of letting water flow through. The presence of cracks in the asphalt surface can supply large quantities of water to the lower layers, and potentially, for a road in conditions that need intervention, all the rainfall can infiltrate through the cracks. The intensity of rainfall is important only until the maximum pavement crack capacity is reached. Beyond such a point the duration of the rainfall becomes more important than the intensity. The presence of water in the pavement surface tends to increase oxidation, and thus ageing, of the bonding matrix, which in turn becomes more brittle; the consequences are stripping, ravelling and an increase in cracks. However, asphalt deterioration, crack formation and their dependency on water condition is not completely clear yet, and therefore will need some research during the present project.

Other than percolating through the surface, water can reach the subgrade by migrating from lateral shoulder slopes and verges, or by seepage from the groundwater. The relative importance of the different phenomena and routes depends on the materials involved, the climate and the topography of the terrain.

The presence of water in the subgrade is even more important in cold climates. At temperatures below zero, frozen water, although giving strength, can also lead to non-uniform heave, with consequent road roughness and driving discomfort. Frost heave is commonly related to the presence of fines. When the pavement temperature passes from negative values to temperatures close to zero, and the soil starts to melt, thawing can develop, that makes the soil particularly weak and the road vulnerable. Thawing is a typical phenomenon that occurs during spring in cold climate regions, but because of the increasing tendency of the temperatures, it tends to appear earlier in the year and, often, also during warm winter days. Some regions, traditionally suffering from intermittent freezing (e.g. UK, northern France, Belgium, Netherlands, northern Germany, Denmark) are expected to benefit, in this respect, under climate change with frost penetration (and, thus, thaw problems) being reduced.

Pavements with thick asphaltic layers transmit less stresses to the soil underneath and are less affected by cracks through the whole depth, and thus are less sensitive to moisture changes. A study of the extent to which the asphalt thickness relates to the sensitivity to moisture content needs to be addressed during the P2R2C2 project, and this will be done by means

of models. Also the sensitivity to moisture change of the material beneath the surface will need to be investigated, and this will be done mainly with laboratory tests. However, a lot of work has already been done in the past regarding the study of the pavements' mechanical behaviour in relation to moisture content, and can be found in the literature. The most frequently used instrument to measure pavement capacity *in-situ* is the Falling Weight Deflectometer (FWD). Based on field data, some analytical studies on the relationship between water and pavement performance have been performed in previous researches. Experimental field and laboratory data have allowed the development of models aimed at describing the various aspects of the water infiltration/road performance relationship, for example a model that simulates water movement below the pavement surface and in the presence of drains, another that simulates rainfall percolation into cracks. Frost heave and thaw weakening are phenomena particularly difficult to model, due to the complex processes involved. Nonetheless, some attempts have been successfully made. One of them is the FROSTB model, which seems to give good prediction. As the presence of water within the road structure is one of the main factors responsible for road deterioration, good drainage is very important. This can be achieved mainly: • with a granular layer at the bottom of the construction that is permeable enough to drain water as quickly as possible; • with a drainage pipe system of adequate capacity and having adequate falls to outlets; • with a proper road surface shape, able to let rainfall water flow away and not infiltrate. Different drainage systems will be investigated during the P2R2C2 project.	

Milestone, date: W.P. 2.2, 30/09/09	**Assessment by PSG**
The aim of this working package is to study, through literature review and, if necessary, through laboratory tests, the wetting-drying effect on subgrades. This milestone is meant to be finished by the end of November. This working Package is being developed mainly by ZAG.	**RED** **AMBER** **GREEN**
Results:	
Some important aspects that need further investigation have arisen from the literature review so far. The soil undergoes processes of drying and wetting as a result of climatic changes. In the highway and highway environment, much of the road constructions are in a partially saturated condition. It is important to know the nature of the soil-water characteristic curve of an unsaturated soil in order to predict the water content changes when the soil is subjected to drying or wetting. An unsaturated soil in the field is often subjected to more	

significant and frequent changes in matric suction, than in total stress. We collected some typical soil water characteristic (SWCC) and compared them based on a different water content.

For most soils the soil water characteristic curve (SWCC) shows hysteresis. The SWCC for drainage and wetting conditions differs and thus characteristic~~s~~ curves exhibit hysteresis between drying and wetting process.

For natural subgrade soils two special conditions have to be checked; the potential for swelling clays and for collapsible silts. Those two types of soils are particularly sensitive to drying - wetting process in the ground.

Swelling soils exhibit large changes in soil volume with changes in soil moisture. The potential for volumetric swell of a soil depends on the amount of clay, its relative density, its mineralogical composition, the compaction moisture, permeability, location of the water table, presence of vegetation and trees and overburden stress.

Collapsible soils exhibit abrupt changes in strength at moisture contents approaching saturation. When the soil is dry or at low moisture content, collapsible soil~~s~~ is a stable deposit. At high moisture contents, these soils collapse and undergo sudden decreases in volume. The collapsible state is characterised by a low relative density, a low unit weight, and a high void ratio.

The relationship between rainfall and moisture content will be looket at in more depth, starting from the preliminary conclusions from W.P. 1.2, in particular, data from landslide on which the research work was made by ZAG need to be looked at.

<table>
<tr><th>Milestone, date: W.P. 2.3, 30/09/09</th><th>Assessment by PSG</th></tr>
<tr><td>The aim of this working package is to study, through literature review and laboratory tests, the behaviour and the ageing of current asphaltic materials at different temperatures and the effect of water. This milestone is going to start in October and is meant to be finished by the end of February. This working package is going to be developed mainly by Inge Hoff (SINTEF).</td><td rowspan="3">RED
AMBER
GREEN</td></tr>
<tr><td>Results:</td></tr>
<tr><td>A draft plan has been developed; it involves literature review oft he following subjects:
• Stripping
• Unravelling of porous asphalt
• Aging of binder – binder properties
• Resistance to permanent deformation
• Relevant laboratory test methods
• Experience from field trials</td></tr>
</table>

Depending on the outcome of the literature review it might be necessary to perform some supplementary laboratory testing. The laboratory testing will in that case be planned later.	

Milestone, date: W.P. 2.4, 30/09/09	**Assessment by PSG**
This working Package, to be developed mainly by Jouko Törnqvist (VTT), will study the freeze-thaw ageing of both the soil and of the unbound pavement. It will start in October and will end at the end of February.	**RED AMBER GREEN**
Results:	
No results available yet.	

Milestone, date: W.P. 2.5, 30/09/09	**Assessment by PSG**
Development and testing of alternative materials for the subbase and subgrade layers will be studied in this milestone by the University of Nottingham. The work will involve both literature review and laboratory tests.	**RED AMBER GREEN**
Results:	
A first assessment of the possible tests needed has been done. So far, the most suitable test seems to be a plate test on a box; there is also the possibility that it will be performed in the Nottingham Pavement Test facility. An alternative seems to be CBR tests.	

Milestone, date: W.P. 3.1, 30/09/09	**Assessment by PSG**
Computational analyses of a selection of pavements, subgrade types and materials under a range of climates. This milestone will be mainly developed by Inge Hoff (SINTEF). Starting date: July 2009; end date: March 2010.	**RED AMBER GREEN**
Results:	
Some first, simple analyses of the life expectancy of a typical pavement subject to increased temperatures have been performed. These will be the starting point for the next analyses.	

Milestone, date: W.P. 4, 30/09/09	**Assessment by PSG**
This work package will deal with the computational analysis of water flow in pavements and the possible ways to reduce the presence of water below the road surface. W.P. 4.1 and 4.2 will be treated together. The University of Nottingham is the main responsible for it. The starting date is September 2009, a final report to be expected by the end of March 2010.	**RED AMBER GREEN**
Results:	
A draft plan has been developed so far (although it might be subject to changes): 1) Study of the sensitivity of subgrade soil moisture content to changes	

in rainfall 2) Study of the sensitivity of subgrade to frost heaving and thawing 3) Simulation modelling and, possibly, empirical experimentation for validation of the remediation methods that seem best among the following ones: • use of crushed, angular, aggregate with a large and steep grain size • Improve drainage system! • use of sealing barriers • mix aggregate with hydraulic binders • mix aggregate with foam bitumen • improve mastic properties of surface asphalt • improvement of asphalt mix design • use of rubber in the asphalt mix • real-time deflection measurements (thawing problem) 4) A third possible matter that might be worth investigating is the effect of the increased groundwater level. This can be done following these steps: • Identifying those areas, among the countries part of our study, where the groundwater level might represent a problem if increased (i.e. those areas where groundwater level is already relatively high) • Making a prediction of the raise of groundwater level in such places • Simulation of the effects of such a raise (this might be done by modifying the model that will be used for rainfall). • Study possible solutions. Simulation Model that is proposed to be used: Groundwater Vistas (MODFLOW, U.S. Geol. Survey).	

Milestone, date: W.P. 5, 30/09/09	**Assessment by PSG**
W.P. 5 will deal with the formulation of advise on future rehabilitation and maintenance. This will be mainly developed by ZAG. It is meant to start in March 2010 and will end with the end of the project (July 2010).	**RED** **AMBER** **GREEN**
Results:	
No results available yet.	