ERA-NET Road – Design

Rapid and Durable Maintenance Methods and Techniques

Final Report

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This project was initiated by ERA-NET ROAD.

Executive summary

The overall aim of the trans-national joint research programme **ERA-NET Road 2011 "Design – Rapid and durable Maintenance Methods and Techniques"** was to improve road conditions for the short- and long-term. There is significant potential for improvement of traditional road maintenance approaches through application of better material technologies, effective, safe, environmentally friendly methods and standards for road maintenance in order to prolong the service life of road and other road elements. Therefore, the programme objectives were developed with the concepts of:

A) Safety Optimising Road Network Availability during Maintenance

B) Durable Construction and Maintenance Methods

C) Strategies for Reducing Maintenance Costs

These objectives were developed following a series of workshops involving specialists from each of the partner road authorities. It was recognised that the traditional approach without pan-European cooperation, often resulted in duplication of research. This research programme sought to redress the problem by integrating these issues into an optimised management framework.

Six projects were funded in the research programme and were carried out during 2011-2013. The tools, methodologies and models developed in the projects provide road administrations with extensive knowledge on:

- How to set appropriate and effective contractual limits for an efficient management of road works, taking into account road user safety and road worker safety, as well as network performance;
- What are the most durable construction and maintenance methods for damage repairs of potholes, which occur after hard winters;
- What are the requirements and benefits of using recycled polymer modified asphalt into new high quality surface layers, using hot mix recycling, on the road network;
- How to monitor and assess road maintenance needs across Europe, using Floating Car Data methodology;
- How to optimally identify and select road lengths maintenance candidates, taking into account durability, safety, comfort and the environment;
- How to improve performance prediction modelling for asphalt road pavements, by integrating material-science into prediction models, towards a more efficient pavement management system.

STARs (Scoring Traffic at RoadWorks) aimed to enable maintenance contract authorities across Europe to set appropriate and effective contractual limits for the impacts of road maintenance and construction works on traffic.

The output was a maintenance tool for an efficient management of road works, taking into account road user safety, road worker safety and network performance. The existing tool is considered "proof of concept", but can be used in its current form to evaluate a motorway road works scheme and associated traffic management strategy in terms of road user safety, road worker safety and traffic performance.

POTHOLE (Durable Pothole Repairs) aimed to address the need of road agencies for durable construction and maintenance methods for damage repairs which occur after hard

winters (due to repeated frost-thaw cycles).

The main outcome of the project was a set of guidelines that present an extensive overview of the available materials and repair techniques for potholes, to give national road administrations an insight in what are the best solutions for their specific needs.

RECYPMA (Possibilities for high Quality Recycling of Polymer Modified Asphalt) focused on investigating the possibilities for recycling polymer modified asphalt from surface layers into new high quality surface layers using hot mix recycling.

The results showed that using up to 40% high quality reclaimed asphalt from old surface layers with 60% new material in new surface layers will result in a performance comparable to one with 100% new material. The methodology developed in the project shows the possibilities and benefits of using recycled material towards a more effective pavement management system.

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

The output of the project was a web-based maintenance tool along with a graphical user interface – tool based on Floating Car Data technology, for the estimation of pavement quality, load bearing capacity and winter road conditions on a road. The tool is available on the project's website (MobiRoma.eu).

TOOLBOX (A method to select maintenance candidates) focused on the advancement of the development and implementation of practical strategies and tools to assist road authorities in selecting maintenance candidates on their road networks.

The outcome was an Excel-based tool that can help road authorities in identifying road lengths in need of maintenance, by taking into account high level indicators such as comfort, safety, durability and the environment.

InteMat4PMS (Integration of Material-science based Performance Models into Life-cycle Analysis processed in the Frame of PMS) aimed to develop an advanced procedure to improve performance modelling for asphalt road pavements, by integrating material-science into performance prediction models.

The output of the project was the development of a methodology of integrating material science into prediction analysis of pavements, by means of laboratory calibration. The methodology can be applicable for further distress mechanisms such as rutting or low temperature cracking.

The **ERA-NET ROAD** concept encourages the exchange of knowledge between National Road Administrations in Europe and gives them the opportunity to improve the quality of European roads, while reducing costs.

As the joint research programme comes to an end, some general recommendations can be given:

- There is significant potential in optimising and improving the current pavement management systems, as the Design programme has shown;
- Further research work is needed to enhance and further develop the outcomes of the projects;
- The results (tools, models, guidelines) should be disseminated across CEDR member countries;
- Data availability is still an issue and more interaction between the projects would be valuable and would help complement and strengthen the results;

List of Tables

List of Figures

Table of content

1 Introduction

"ERA-NET ROAD – Coordination and Implementation of Road Research in Europe" was a Coordination Action funded by the 6th Framework Programme of the European Commission. The partners in ERA-NET ROAD (ENR) were United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark. Within the framework of ENR, the trans-national joint research programme ENR 2011 "Design – Rapid and durable Maintenance Methods and Techniques" was initiated. The funding partners of this cross-border funded Joint Research Programme were the National Road Administrations (NRAs) of Belgium, Germany, Denmark, Finland, France, Netherlands, Norway, Sweden, Slovenia and United Kingdom. The research budget was 1.8 million Euro and 20 proposals with 84 partners from 17 different countries were submitted.

The overall aim of the programme was to improve road conditions for the short- and long-term. There is significant potential for improvement of the traditional road maintenance approaches through application of better material technologies, effective, safe, environmentally friendly methods and standards for road maintenance in order to prolong the service life of roads and other road elements. Therefore, the programme objectives were developed with the concepts of:

A) Safely Optimising Road Network Availability during Maintenance

B) Durable Construction and Maintenance Methods

C) Strategies for Reducing Maintenance Costs

The objectives were developed following a series of workshops involving specialists from each of the partner road authorities. It was recognised that the traditional approach without pan-European cooperation, often resulted in duplication of research. This research programme sought to redress the problem by integrating these issues into an optimised management framework.

Six projects were funded in the research programme and started in 2011:

- **STARs** – Scoring Traffic at Road works
- **POTHOLE** – Durable Pothole Repairs
- **RECYPMA** – Possibilities for high quality Recycling of Polymer Modified Asphalt
- **MOBI-ROMA** – Mobile Observation Methods for Road Maintenance Assessments
- **TOOLBOX** – A Method to select Maintenance Candidates
- **InteMat4PMS** – Integration of Material-science based Performance Models into Life-cycle Analysis processed in the Frame of PMS

All project reports and deliverables can be downloaded from the ERA-NET website: **http://www.eranetroad.org**.

At the conclusion of the programme, a two-day conference was organised to present the results and overall conclusions of the six projects. The conference was held on January 23rd-24th, 2014 in Vienna, Austria and was hosted by the AIT Austrian Institute of Technology. Three parallel group discussions were carried out, with focus on the implementation of the project results, as well as remaining open questions.

The aim of this report is to summarise the results, conclusions and recommendations from the six projects and emphasise how national road authorities can implement and find the most benefit out of the results.

2 Project descriptions

This chapter presents the six projects selected in the Joint Research Programme. A brief description of the methodologies and results, along with a set of objectives and outcomes can be found for each project.

2.1 STARs – Scoring Traffic at Roadworks

Duration: 01.10.2011 – 31.04.2013

Budget: EUR 314.777

Coordinator: Jill Weekley, Transport Research Laboratory (TRL), United Kingdom

Partners: Belgium Road Research Centre (BRRC), Belgium

Karlsruhe Institute of Technology (KIT), Germany

Trinity College Dublin, Ireland

Swedish National Road and Transport Research Institute (VTI), Sweden

Slovenian National Building and Civil Engineering Institute (ZAG), Slovenia

The aim of the project was to enable maintenance contract authorities across Europe to set appropriate and effective contractual limits for the impacts of road maintenance and construction works on traffic. The output was a maintenance tool for an efficient management of road works, taking into account road user safety, road worker safety and network performance.

Objective	Outcome
Evaluation of generic data requirements for road works	A categorisation of road works in terms of type, location and timing at a European level was performed. This resulted in a 27 parameter combination for the three risk areas considered in the project (road worker safety, road user safety, network performance). (see Deliverable 1 [1])
Data collection for tool input parameters	A bottom-up and top-down approach was used to identify the parameters associated with road work schemes. Fixed and variable parameters to be used as input in the tool were defined. (see Deliverable 2 [2])
Development of risk equations for road worker safety, road user safety, network performance	Standalone equations based on literature and expert opinions were developed for road user safety, road worker safety and network performance. Each equation was based on the input parameters and delivered a risk score. (see Deliverable 4 [3])
Development of an unified metric combining road user safety, road worker safety and network performance	The risk scores for road worker safety, road user safety and network performance were transformed into a normalised and comparable rating to produce the STARs single global rating for road work schemes. (see Deliverable 4)
Development and validation	The tool is considered "proof of concept" but can be used in

of the tool	its current form to evaluate a motorway road works scheme and associated traffic management strategy in terms of road user safety, road worker safety and traffic performance. Five use cases were presented for validation of the tool. (see Deliverable 4)
Build-up of a tool user guide	A guide for users to follow while using the tool was developed. It guides the user step by step using case studies, recommendations and screen shots of the tool. (see Deliverable 5 [4])

In the first stages of the projects, a generic categorisation of road works in terms of type, location and timing was performed. The figure below shows a "cube" of parameter combinations for each of the three risk areas – road worker safety, road user safety and network performance.

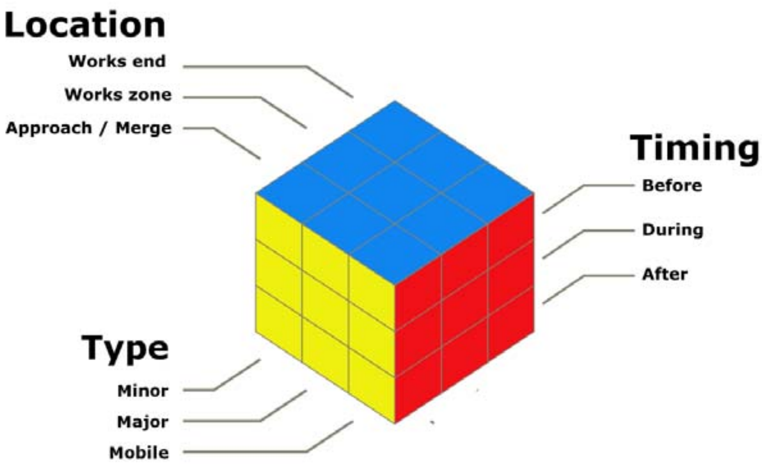

Figure 1 STARs - Parameter combination for all risk areas - Road worker safety, road user safety and network performance

The categorisation of road works provided an initial assessment of the relevant parameters (input data) for the tool. Risk tables were created for the three risk areas (road worker safety, road user safety and network performance) and the parameters were assessed for their relevance to that risk area in each category. The tables were then used to develop a questionnaire for representatives of the national road authorities in order to collect data on best practices, data availability and other significant expertise.

The development of the tool required three main aspects, which also represent the three modules of the STARs evaluation tool.

Input data

A bottom-up approach was used to identify the parameters associated with each road work circumstance. An overview of typical EU works zone layouts and their application was performed through a literature review of national standards and guidelines being in force in six countries. The information collected with the questionnaires was also fed into the description of the layouts. The process resulted in a list of parameters associated with each layout.

A top-down approach was used to consider the inputs required by the three individual risk equations for road worker safety, road user safety and network performance, which were necessary for the tool. Five hyper parameters were identified in this process and included road work size, risk mitigation measures, flow and traffic characteristics.

The final list of parameters that resulted and used as input in the evaluation tool was:

- Fixed parameters: site, country, motorway and road works types, length of whole works, traffic flow, length for advance warning, etc.
- Variable parameters: speed compliance management, delineation, width of open lane, lateral distance between work zone and traffic, etc.

The first module in the tool is used by the user for describing the specific road work scheme to be evaluated. The figure below shows the parameter list available in the tool that the user must complete.

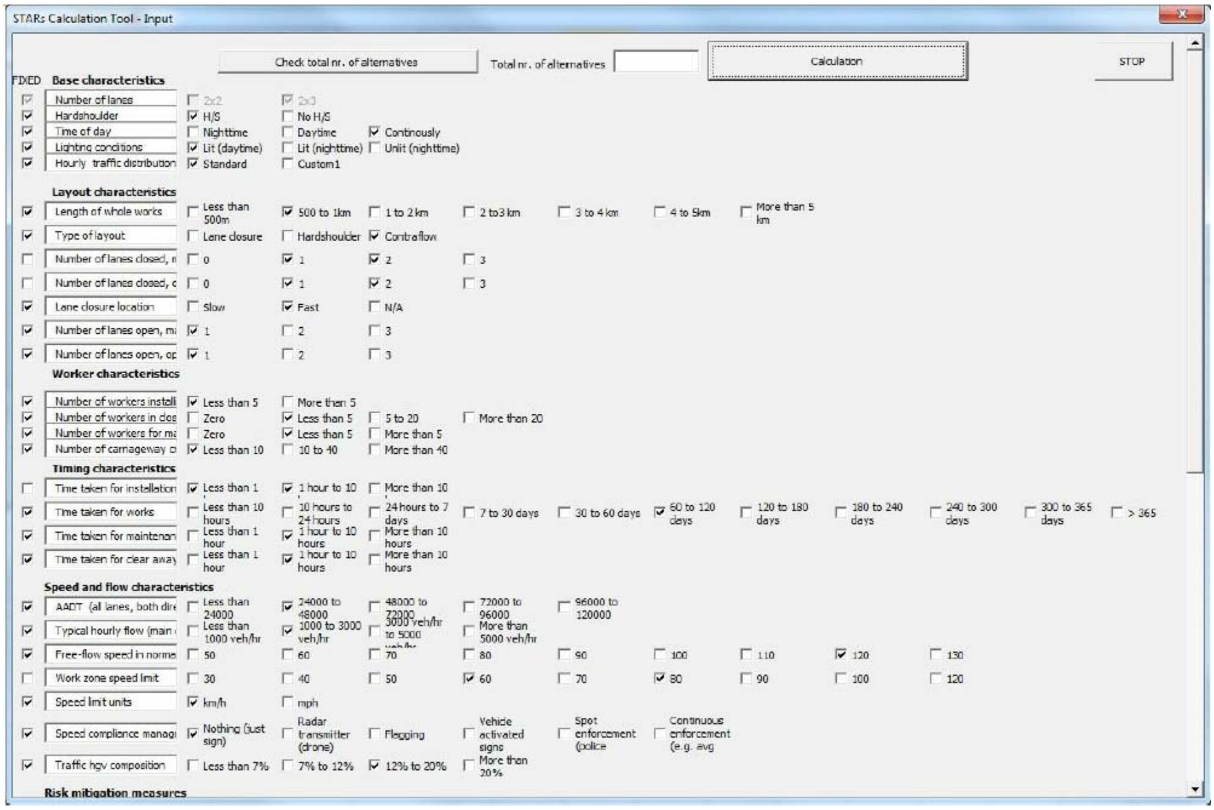

Figure 2 STARs - Parameter selection

Risk equations

The second module of the tool represents the core and contains the risk evaluation equations. Although they are independent equations, they used the same set of input parameters.

The road worker safety equation was developed using established knowledge in the field, as well as expert opinions. It was built on the concept of risk equalling probability of an accident to a worker (dependent on traffic flow and speed characteristics) and the exposure of workers carrying out the activity (dependent on number of workers and time taken). The risk score was multiplied by the “base risk” – a factor representing the inherent risk of the location, i.e. hard shoulder, lighting, etc. A mitigation factor was also taken into consideration, dependent on mitigation measures used at a particular road work being assessed.

The road user safety model took into consideration data taken from literature and used as primary indicator the crash rate at work zones. The risk score was dependent on hyper parameters such as traffic flow and road type characteristics, duration of works and length of work zone. A risk mitigation factor was also taken into account, which included parameters such as the use of warning systems, speed limit enforcements and others.

The network performance model used as primary indicator the time delay in free flow and queue conditions, due to reduced speed through work zones and lane closure reducing capacity respectively. The risk score was dependent on the geometrical properties of different work zone configurations, flow and work zone capacity and queue discharge rate.

STARs single global rating

Based on the first two modules, the tool's output is a set of alternatives – alternative management solutions, each with an associated score for road worker safety, road user safety and network performance. Through a Multi-criteria Solver, a dominance principle is used to rate the alternatives, meaning that if a solution is dominated by another, it is removed from the set of solutions. A marginal utility function for each criterion was applied to transform each score into a normalised and comparable rating for road user safety, road worker safety and network performance. The tool produces a single global STARs rating, using the three criteria scores with weights associated with each marginal utility function (see Figure 3).

		1		2		3
Dominant Solutions	alt 000096		alt 000064		alt 000062	
Overall Stars Rating	* * *	0.5617125	* * *	0.54510763	* * *	0.50580516
Road User Safety	* * *	0.48543369	* * *	0.46714855	* * *	0.42143568
Road Worker Safety	* * * * *	0.80266261	* * * *	0.77110435	* * * *	0.69882836
Traffic Performance	* *	0.39704119	* *	0.39707	* *	0.39715144
Variable Parameters						
Speed compliance managemen	Spot enforcement (police		Vehicle activated signs		Vehicle activated signs	
Delineation	Temporary barrier		Temporary barrier		Temporary barrier	
Lane closure mechanism	Both		Both		Both	
Use of vehicle restraint system:	Low performance		Low performance		Low performance	
Use of physical traffic managem	Transverse pavement mai		Transverse pavement mai		None	
Use of TMA/LMCC	1		1		1	

Figure 3 STARs - Example of "Summary Dominant solutions" worksheet

Five use cases, representative of different road work schemes, were used to validate the tool and assess the impact of varying aspects of traffic management strategies on the three risk areas and on the risk score for the respective scheme as a whole.

The existing tool is considered "proof of concept", but can be used in its current form to evaluate a motorway road works scheme and associated traffic management strategy in terms of road user safety, road worker safety and traffic performance. Further research could help tailor the tool for a specific user in a particular country, or further generalise the tool and include data from multiple countries, therefore allowing comparison between different European countries.

2.2 POTHOLE – Durable Pothole Repairs

Duration: 01.10.2011 – 30.09.2013

Budget: EUR 315.000

Coordinator: Carsten Karcher and Kathrin Kubanek, Karlsruhe Institute of Technology (KIT), Germany

Partners: Danish Road Institute (DRI), Denmark

Forum of European National Highway Research Laboratories (FEHRL), Belgium

Transport Research Laboratory (TRL), United Kingdom

University of Zilina (UNIZA), Slovakia

University of Twente (UT), The Netherlands

Slovenian National Building and Civil Engineering Institute (ZAG), Slovenia

The main objective of the project was to address the need of road agencies for durable construction and maintenance methods for damage repairs which occur after hard winters (due to repeated frost-thaw cycles). By studying existing techniques, materials and best practices of European markets, together with tests and evaluations from trial sites in Denmark, Slovenia and UK, a set of guidelines was developed to aid road agencies in enhancing their maintenance needs.

Objective	Outcome
Definition of term “pothole”	A proposed definition of potholes along with relevant descriptions was set, after gathering knowledge from the involved partners and feedback from a web-based questionnaire. (see Deliverable 1 [5])
Selection of tests and evaluation methods of pothole repair materials	A list of material requirements that need to be assessed in order to ensure durability was compiled, as well as a list of test methods used for the respective assessments. (see Deliverable 2 [6])
Evaluation of existing standards, materials and methods for pothole repair	The assessment of standards, methods and materials was performed by using not only European knowledge, but also from the US and Africa. The evaluation resulted in a classification and description of pothole materials and repair procedures. (see Deliverable 3 [7])
Evaluation of techniques and materials from existing trial sites	Based on an analysis of trial sites from Denmark, Slovenia and United Kingdom, an overview of repair materials for potholes classified by generic material types was performed. Furthermore, a categorization of durability for pothole repair materials was achieved. (see Deliverable 5 [8])
Laboratory testings of selected materials	Three types of materials (hot asphalts, cold asphalts and synthetic-binder mixtures) were selected and analysed in terms of workability, indirect tensile strength, water resistance and sensitivity to freeze-thaw cycles. (See Deliverable 5)
Life Cycle Cost and Benefit Analysis	A life cycle cost and benefit analysis (LCCBA) on different strategies for the repair of potholes, consisting of different

	materials and techniques was performed, to aid road agencies in finding the most cost-effective repair strategy applicable to a specific scenario. (see Deliverable 5)
Development of guidelines	A set of guidelines was developed to present an overview of materials and procedures for pothole repair, providing support to stakeholders in durable pothole repairs and enhance their maintenance needs. (see Deliverable 5, Annex [9])

At the beginning of the project, a web-based questionnaire was sent to experts and road administration representatives to gather information about potholes and their definition around Europe, best practices in pothole repair materials and techniques and existing pothole repair trials across Europe. Based upon this and expert knowledge of the involved partners, a definition of “pothole” was developed, which takes into account also the mechanisms of pothole development:

Pothole – a local deterioration of the pavement surface in which the material breaks down in a relatively short time and is lost causing a steep depression.

An extensive literature review was performed to find out what are the most relevant test methods for pothole repair materials and techniques. Compliance checking for an entire road section is impractical, therefore the materials and techniques used for repair need to be evaluated through specific procedures. A list of material requirements that needed to be assessed in order to ensure durability was compiled, as well as a list of test methods used for the respective assessments. For example, in order to test compactibility in adverse conditions, the method EN 12697-10 at low temperature is employed.

An evaluation of the existing standards, methods and materials for pothole repair in Europe and outside was then performed. The research included a literature search, as well as direct approaches to road authorities, contractors, producers, suppliers and users. The assessment resulted in a classification and description of pothole materials and repair procedures. The main types of materials used for pothole repair are:

- Bitumen – based cold-mix materials (cold-mix asphalt CMA)
- Bitumen – based hot-mix materials (hot-mix asphalt HMA)
- Cement based materials

And the main types of pothole repair techniques are:

- Temporary repairs
- Semi-permanent procedures
- Permanent or more durable repairs

To further enhance the findings from the literature and based on the feedback from the first questionnaire, a second questionnaire was sent out to selected persons regarding existing trial sites for pothole repairs. Trial sites from Denmark, Slovenia and United Kingdom (see Figure 4) were assessed in terms of repair materials and techniques, evaluation methods of repair performance, types of damage specific to a type of material and evaluation methods of durability.

Based on this analysis, an overview of repair materials for potholes classified by generic material types was performed (see Table 1). Furthermore, a categorization of durability for pothole repair materials could be achieved:

- ❖ Category I: Durability less than 1 year (short-term durability)
- ❖ Category II: Durability between 1-3 years (medium-term durability)
- ❖ Category III: Durability more than 3 years (long-term durability)

Figure 4 POTHOLE – Trial site Denmark

Table 1 POTHOLE - Overview of repair materials for potholes classified by generic material types

	Hot applied asphalt	Cold applied asphalt	Cement	Synthetic binder
Estimated durability	Cat. I, Cat. II, Cat. III	Cat. I, Cat. II	Cat. I, Cat. II	Cat. I, Cat. II, Cat. III
Equipment	Comprehensive	Limited	Limited	Limited
Limitations for application	None	None	Pothole < ½ m	Temperature > 10 °C
Ready for traffic	Shortly after application	Shortly after application	< 3 h after application	< 3 h after application
Working environment	Special education	None	None	Special education
Possibility of recycling	Yes	Yes	No	No
Typical type of damage	Cracks in repair, adhesion failure, immersed chippings	Loss of material, fretting	Cracks in repair, adhesion failure	Cracks in repair, adhesion failure, cracks in the pavement, loss of chippings, loss of material

The knowledge gained from the existing trials was used to determine laboratory testing – to be used for the correct testing of materials for the purpose of pothole repairs. Although it was initially planned to do laboratory testing on 12 repair materials, due to time and resources limitations, only three types of materials (hot asphalts, cold asphalts and synthetic-binder mixtures) were selected and analysed in terms of workability, indirect tensile strength, water resistance and sensitivity to freeze-thaw cycles. The findings enhanced the already existing knowledge and improved the know-how on the requirements of pothole materials.

A life cycle cost and benefit analysis (LCCBA) for different strategies for the repair of potholes, consisting of different materials and techniques was performed to aid road agencies in finding the most cost-effective repair strategy applicable to a specific scenario. 12 repair strategies were applied to four scenarios (representing typical but contrasting repair situations). Recommendations were given, although road agencies have to consider the peculiarities of their road networks in the LCCBA, in order to obtain managerial relevant results.

Based on all the research performed a set of guidelines was developed. The guidelines offer stakeholders aid in dealing with pothole repair and the different possibilities in this context. An overview of materials and procedures for pothole repair is given, thus providing support when deciding which combination to choose according to the actual need of durability. Furthermore, different repair strategies are explained based on the conducted LCCBA and recommendations are provided. At the end, examples of application of different materials are given.

2.3 RECYPMA – Possibilities for high Quality Recycling of Polymer Modified Asphalt

Duration: 01.10.2011 – 30.09.2013

Budget: EUR 315.000

Coordinator: Jos Wessels, MSc. MBA, The Netherlands Organization for Applied Scientific Research (TNO), The Netherlands

Partners: Danish Road Directorate (DRI), Denmark

Delft University of Technology (TU Delft), The Netherlands

University of Zilina (UNIZA), Slovakia

The aim of the RECYPMA project was to investigate the possibilities for recycling polymer modified asphalt from surface layers into new high quality surface layers using hot mix recycling. The results showed that using up to 40% high quality reclaimed asphalt from old surface layers in new surface layers will result in comparable asphalt performance. Economic and environmental benefits were also estimated and deemed to be significant.

Objective	Outcome
State of the art on recycling of polymers present in reclaimed asphalt (RA)	Literature reviews and dedicated questionnaires helped gain significant knowledge on recycling of polymers, laboratory extraction methods and laboratory mixing methods. (see Deliverables 2.1 and 2.2 [10])
Evaluation of properties of aged polymer modified binders (PMB)	Binders extracted from three types of reclaimed asphalt (RA) were combined with two types of virgin binders in 15% and 40% ratios and evaluated in terms of viscosity, softening point, penetration, etc. (see Deliverable 3.1 [11])
Evaluation of asphalt mixtures using reclaimed asphalt containing polymer modified binder	Three asphalt mixes underwent a series of tests, to evaluate the effect of using RA containing polymer modification on asphalt properties. Water sensitivity, wheel tracking, stiffness and fatigue tests were carried out according to the relevant European standards with good results. (see Deliverable 6 [12])
Microscopy analysis of RA and asphalt mixes	Microscopy analysis of thin and plane sections showed that polymer is still present in the binder of all RA materials. The analysis of the asphalt mixes showed some inhomogeneity in the mixtures and further research is needed for full scale plant produced mixes. (see Deliverable 6)
Environmental and economic benefits of asphalt using polymer modified RA	Life Cycle Analysis and Life Cycle Cost analysis were performed to show the potential benefits that recycling of asphalt containing PMB could have. (see Deliverable 6)

A review of the state of the art regarding recycling of polymers present in reclaimed asphalt (RA) was performed. Through literature reviews as well as a dedicated questionnaire sent out to leading laboratories and research institutions in Europe, the aim was to gain knowledge on three important points: laboratory extraction methods of Polymer Modified Binder (PMB), conditions for laboratory mixing and experience with utilising PMB containing RA. The extensive literature review led to several conclusions and decisions for the next steps in the project (see Table 2).

Table 2 RECYPMA - Overview of literature results

Practical laboratory extraction methods that will allow characterisation of the bulk properties of an aged polymer modified binder (PMB)	It was decided to use Dichloromethane as solvent for the extraction and recovery. The extraction will follow EN 12697-1 for the extraction and the use of rotary evaporator in accordance with EN 12697-3 for the recovery of the binder.
Conditions for laboratory mixing, as opposed to full scale handling of materials in asphalt plants	A laboratory mixing procedure consisting of several steps was formulated. A specific order must be followed, and adaptations to the local conditions must be taken into account. The steps are: Mix dry virgin aggregates 30s. Add RA and mix 30s. Add new binder and special fillers and mix 90s. If necessary, the duration of the last step can be prolonged to achieve full coverage of the aggregates.
Experience with utilisation of polymer modified bitumen (PMB) containing RA	Full scale recycling of old polymer modified asphalt is still in its infancy. The state of the art revealed that material handling from production of the reclaimed polymer modified asphalt and pre-processing needs further improvement to fully utilise its potential.

Based on the findings of the literature review, a methodology was developed to evaluate the rheological and chemical properties of aged polymer modified binder. Three types of reclaimed asphalt were harvested from Denmark (Stone Mastic Asphalt), the Netherlands (Porous Asphalt) and Slovakia (Asphalt Concrete), all containing SBS-PMB (Styrene-Butadiene-Styrene – Polymer Modified Bituminous Binder).

Three different types of asphalt mixes were designed and produced for laboratory testing. Five combinations of virgin material and reclaimed asphalt were used for each type of asphalt mix, by using 0%, 15% and 40% RA. Two virgin binders were used: Paving Grade Binder (PGB) and Polymer Modified Binder (PMB).

In order to assess the performance of the binder in new asphalt mixes containing virgin and reclaimed binder, the extracted binders from the RA were blended in the laboratory with virgin binder and then verified using microscopy. Various tests were performed to evaluate penetration, softening point, DSR (Dynamic Shear Rheometer) master curves, viscosity, GPC (molecular size analyses) and FTIR (functional chemical groups). The results showed that polymer behaviour is still visible in old binders and that blended polymer modified binders can behave similar to virgin polymer modified binders.

To investigate the effect of using RA containing polymer modification on the properties of asphalt, multiple laboratory tests were then performed on the asphalt mixes.

- The water sensitivity test that gives information on the durability with respect to ingress of water showed that all mixtures met the requirements for surface layers.
- The wheel tracking test that provides an estimate of the resistance to rutting showed no rutting for all polymer modified binders. The mixtures with RA and PMB showed a similar performance to the benchmark PMB mixture (0% RA). The mixture with virgin PGB without RA showed a significant amount of rutting, while the mixture with the PGB and 40% RA showed a better performance.
- The stiffness and fatigue tests that give insight in the structural life expectancy and the integrity of the material showed that the mixtures with reclaimed asphalt containing PMB had a higher stiffness compared to the mixtures without RA. This

could be an advantage because a larger stiffness leads to a higher bearing capacity. However, it could also result in brittleness at low temperatures. Further tests on low temperature cracking and properties should be performed in the future for in-depth investigation.

- The fatigue tests were only required for the Slovakian mixtures. The mixture with virgin PMB with no RA was most fatigue resistant and the addition of RA led to a reduced performance. The addition of RA to the PGB mixture improved fatigue resistance.

Based on the results from the laboratory tests, it is assumed that recycling of reclaimed asphalt from surface layers into new surface layers will result in comparable asphalt performance for surface layers, if recycling levels up to 40% are used. However, further investigation is needed to confirm this hypothesis, as a limited number of asphalt mixes were tested with respect to a limited amount of performance characteristics.

Furthermore, microscopy analysis of thin and plane sections was performed to describe the three RA materials extracted and to provide a visual assessment of all new asphalt mixes (with and without RA, with PGB and PMB). Figure 5 is a microscopic view of asphalt concrete (AC11, Slovakia) with PMB and 40% RA. The yellow spots are indicative of the presence and dispersion of the SBS (Styrene-Butadiene-Styrene) polymer. Some inhomogeneity was observed in the mixing, as a clear distinction between the old and new mortar was observed. As a better homogeneity is expected to result in better performance, for future research it is recommended to investigate with microscopy analysis the level of mortar inhomogeneity of full scale plant produced mixes.

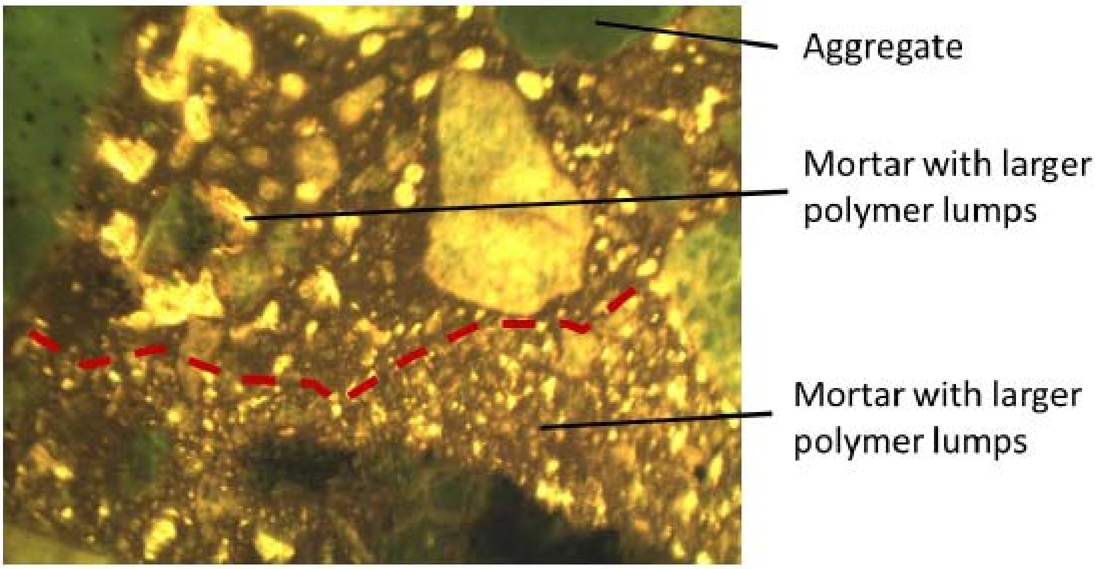

Figure 5 RECYPMA – Microscopy view of Asphalt concrete 11 with PMB and 40% RA

In order to quantify the potential benefits of recycling of asphalt containing PMB, an analysis of the environmental and economic impacts was performed. Life Cycle Analysis and Life Cycle Cost Analysis were performed for the total recycling process, including all materials and processes. The analyses showed that the effect of using recycled material on the environment is significant. Using 15% recycled material in new mixes could reduce the loading by approximately 10%, while 40% recycled material in the mix could reduce the load by approximately 25-30%. The cost analysis showed that the recycling percentage has a distinct influence on the costs. For example, 40% recycled material in the mix could reduce the Life Cycle Cost of polymer modified asphalts by approximately 10-18%. It must be noted that the binder is a dominant factor, as it determines 70% of the material costs.

2.4 MOBI-ROMA – Mobile Observation Methods for Road Maintenance Assessments

Duration: 01.09.2011 – 31.01.2013

Budget: EUR 340.000

Coordinator: Pirkko Saarikivi, Foreca Consulting Ltd, Finland

Partners: Klimator AB, Sweden

Semcon AB, Sweden

Pöyry Infra GmbH, Germany

The project's key objectives were to develop, test and evaluate improved, affordable and moderate-cost road condition and performance assessment techniques, which offer new effective tools for monitoring and assessing maintenance needs across Europe. A web-based maintenance tool, along with a graphical user interface was developed and tested in a pilot project for mobile pavement quality measurements in Sweden, Denmark, Germany and Czech Republic. The results show that Floating Car Data technology is a reliable method for complementing present road monitoring methods.

Objective	**Outcome**
Evaluation of state of the art on road monitoring devices and techniques	An overview of different road monitoring techniques was performed including fixed and mobile detection methods. (see Deliverable 1 [13])
Collection of data, fusion and analysis	Pavement quality, spring thaw and slipperiness data was collected from multiple sources and analysed through various validation algorithms. The data provided the input for the maintenance tool developed in the project. (see Deliverable 2 [14])
Development of the graphical user interface	A map-based graphical user interface was developed for the tool, for operators to quickly and efficiently estimate pavement quality, load bearing capacity and winter road conditions on a road. (see Deliverable 3 [15])
Evaluation of maintenance tool and cost/benefit analysis	The tool was evaluated in terms of the national and trans-national benefits, through interviews with various experts and road administrations, This resulted in a series of conclusions and key recommendations for future work. A general cost/benefit analysis was also performed to emphasise the high potential of FCD technology in road transport. (see Deliverable 4 [16])

The project started with a review on the background and state of the art of mobile road condition measurements using satellite positioning techniques, Floating Car Data (FCD) and CAN-bus data. Additionally, best practices across Europe and outside were reviewed to gain knowledge on the current devices and methods used for road monitoring. Other mobile road measurement projects were also reviewed such as SRIS (Slippery Road Information System), BiFi (Bearing information through vehicle intelligence) and INTRO (Intelligent Roads).

The development of the maintenance tool required data collected during various times of a year and in various traffic conditions. Three main data types were used as input for the tool: spring thaw detection, winter road conditions (slipperiness) and pavement quality estimation.

Due to the amount of data needed, other on-going road monitoring projects were also used, to facilitate both the development and evaluation of the maintenance tool. All data was collected using the FCD methodology.

Pavement quality

The pavement condition measurements were performed to validate both the pavement quality algorithms and the web-based maintenance tool. The validation of the algorithms was done by comparing the collected data with laser measurements from the Swedish Transport Administration. The parameters available for validation were International Roughness Index (IRI), Rutting depth, Macro texture MPD (Mean Profile Depth) right, Macro texture MPD centre, Macro texture MPD left. The output generated by the algorithms was a grade from zero to ten, ten representing good quality. The outcome of the validation of the pavement quality algorithms showed that the MOBI-ROMA pavement quality grade is closely related to IRI.

The validation of the maintenance tool was done with CAN-bus data collected in several countries in all four seasons, in different weather conditions and on different pavement qualities. The measurements were done sporadically during the project with a Volvo V70 in Sweden, Germany, Norway, Czech Republic, and Denmark and the measured distance was over 7000km. Due to the need of larger quantities of data, a dedicated hardware unit developed in the BiFi project was also used. The pavement quality grade is shown as a set of colours in the web-based maintenance tool. The table below shows an attempt at defining the correlation between MOBI-ROMA pavement quality grade and IRI.

Table 3 MOBI-ROMA - Correlation between pavement quality grade and IRI

70 / 2000-4000 (km/h / vehicles/day)		
MOBI-ROMA color	MOBI-ROMA grade	IRI (mm/m)
	≤ 1	≤ 2.2
	2	≤ 3.3
	3	≤ 3.4
	4	≤ 3.6
	5	≤ 3.9
	6	≤ 4.1
	≥ 7	> 4.1

Spring thaw

The spring thaw data for the tool was taken from the project BiFi. Sensors such as GPS, 3G/GPRS and accelerometers were mounted in postal delivery vans (Fiat Fiorino) and collected measurements in various municipalities in Sweden. The routes chosen were picked to get the maximum coverage of gravel roads possible.

The analysis algorithm contains four main parts that have veto power when a spring indication is generated: surface softness, curve detection, gravel detection and velocity interval. The output can be seen in the maintenance tool as colour coded spring indications attached to geographical positions.

Slipperiness

Data regarding slippery roads was taken from the project SRIS. On-board hardware (using ABS and ESP activation signals) mounted in 100 vehicles (Volvo V70s and Saab 9-5s) collected slipperiness measurements in the winters of 2006-2007 and 2007-2008.

The slipperiness algorithm uses three models for the analysis. A road weather model uses meteorological information to divide the road network in risk categories (not slippery, slippery and very slippery). The output of the road weather model is then compared to the output of the vehicle model (which is the floating car data). The final result is presented by an interpreter model which makes the final adjustments.

Since all collected data during the project was geographically positioned, the Graphical User Interface was developed on a map application, in order for operators to quickly and efficiently estimate pavement quality, load bearing capacity and winter road conditions on a road. The maintenance tool GUI can be seen in Figure 6.

Evaluations and user interviews were performed in order to assess the potential benefits of the developed maintenance tool and its use in complementing the present methods for short term and long term road assessments. A general cost/benefit analysis (CBA) on the use of FCD in road maintenance was also included, as well as an assessment of the national and trans-national benefits compared to the present methods. An estimation of 3000 Euro was reached for each vehicle in a FCD fleet. Therefore a fleet of 100 vehicles would cost 300.000 Euro. In contrast, the total weather-induced costs for European road transport were estimated to 41 billion Euros annually (EWENT project – Extreme weather impacts on European transport). For example, in Finland a reduction of wintertime accidents by 1% would imply annual benefits of approximately 40 million Euros.

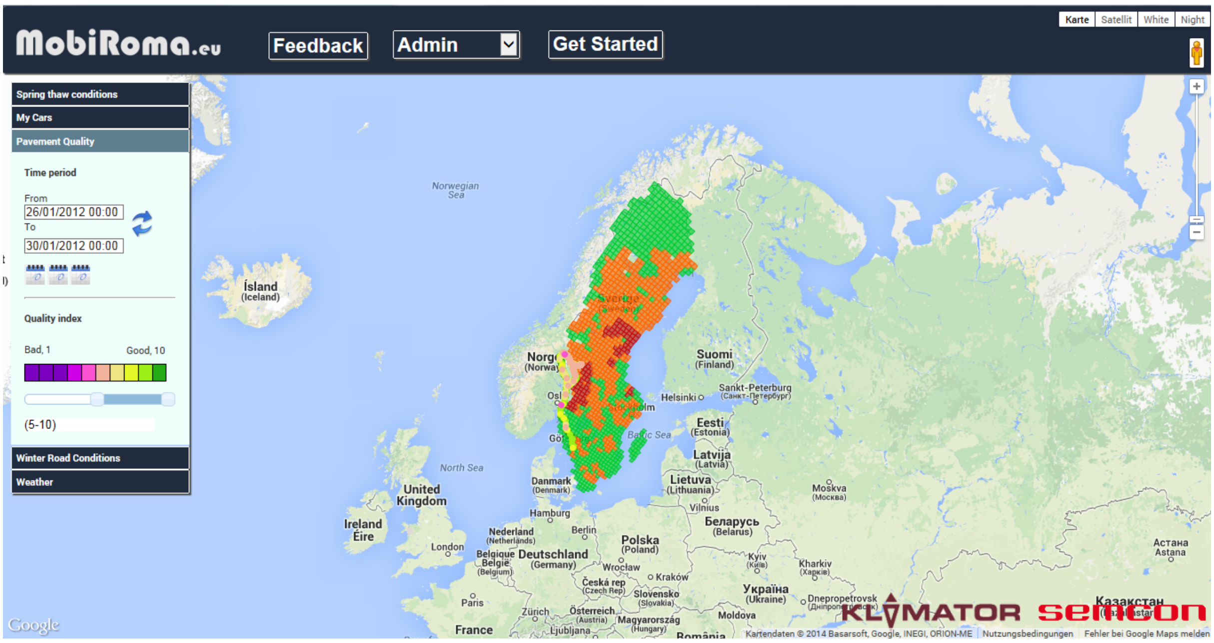

Figure 6 MOBI-ROMA - Maintenance tool GUI

The main results and recommendations of the project were:

- The maintenance tool has a complementary character and will not substitute current monitoring methods (e.g. laser measurements);
- The MOBI-ROMA service could be used for European road maintenance, but the needs differ depending on the local road climate conditions (e.g. gravel roads monitoring is an issue for Nordic countries);
- The accessibility to CAN-bus data is still a concern and may require a European wide action;
- Large fleet of vehicles would be necessary for the coverage of major roads in Europe;
- Data standards should be developed at European and international level, in order to have the possibility of mixing data from different types of vehicles and mobile measuring equipment;
- Low cost of communication between vehicles and road side equipment as well as data analysis centres is required;

- There is great potential in developing road user warnings based on mobile monitoring data. Just a small reduction of accidents (1%) due to improved road condition data could lead to substantial benefits at a European scale.

The maintenance tool is available and can be found on the MOBI-ROMA project website (MobiRoma.eu).

2.5 TOOLBOX – A method to select maintenance candidates

Duration: 20.10.2011 – 30.10.2013

Budget: EUR 255.127

Coordinator: Leif Sjögren, Swedish National Road and Transport Research Institute (VTI), Sweden

Partners: Transport Research Laboratory (TRL), United Kingdom

Austrian Institute of Technology (AIT), Austria

Centre of Technical studies and Equipment (CETE), France

WSP Group, Sweden

The aim of the project was to advance the development and implementation of practical strategies and tools to assist road authorities in selecting maintenance candidates in their road networks. The outcome was an Excel-based tool that can help road authorities in identifying roads in need of maintenance, while taking into account high level indicators such as comfort, safety, durability and the environment.

Objective	Outcome
Review of frameworks, tools and models used in PMS	The current state of the art was reviewed to identify available technical parameters used for the selection of maintenance candidates. (see Deliverable 1 [17])
Development of models for safety, durability, comfort and environment triggers	Individual models for high level indicators (safety, comfort, environment and durability) were developed. The comfort and durability models were developed in the project. The safety and environment models were based on similar models from other projects (see Deliverable 2 [18]).
Development of an Excel-based tool	A spreadsheet-based tool was developed in Excel that uses the models for safety, durability, comfort and environment and combines them, with user defined weightings, to form the Combined Condition Indicator (CCI). The index is then used by the tool to identify potential maintenance candidates. (see Deliverable 3 [19])
Life Cycle Cost Analysis	A Life Cycle Cost Analysis was incorporated in the tool, to optimize maintenance schemes trying to meet different objectives such as budget, LCC, safety, environment and comfort, taking into consideration road users' benefits and deliver road owner life cycle costs. (see Deliverable 4 [20])
Demonstration and validation of the tool	Motorway data from UK, Sweden, Austria and France was used to demonstrate the applicability of the ToolBox tool. The results showed that most of the lengths in need of maintenance that were identified by the ToolBox tool could also be identified by maintenance engineers. (see Deliverable 4)

A review of the current state of the art regarding the tools, models and frameworks used in current pavement management systems (PMS) was performed to identify available technical parameters used for the selection of maintenance candidates. Austria, France, Sweden, UK current best practices were analysed and both similarities and differences were found in the ways the countries select project candidates (i.e. road lengths for maintenance).

Technical parameters such as the International Roughness Index (IRI), rut depth, surface deterioration and friction are most commonly used for selecting lengths for maintenance on the network. The aim of Toolbox was to use a set of higher level indicators such as safety, durability, comfort and environment to make the selection of maintenance candidates. A review was therefore performed to find out, if there are any developed models that combined the parameters needed to obtain the triggers.

Comfort

Comfort is primarily dependent of the longitudinal profile of the road, localized roughness, such as potholes, transversal unevenness and edge roughness. The literature revealed no methodology for combining the technical parameters towards an overall comfort trigger. Therefore, a comfort model was developed by taking into account the methodologies and best practices from Austria, France, UK and Sweden.

Durability

The durability of a pavement can be evaluated by its structural strength, visual deterioration, structural rutting or subsidence and presence of potholes. Similarly, no model was found for the durability trigger and a model was developed during the project.

Safety

Two models were identified that could be used for the safety trigger – ALERTINFRA (Detection of dangerous road configurations, developed by CETE) and MARVIN (Modell zur Abschätzung des Risikopotenzials von Verkehrsinfrastruktur, developed by AIT). A comparison between the two models led to the decision of using the ALERTINFRA model. The software tool uses technical parameters such as curvature, unevenness data, crossfall, gradient, macrotexture and friction to detect dangerous configurations on a road network.

Environment

The environment model included external noise, particulates and other emissions and fuel consumption. No model was identified for noise and therefore one was developed in the project. The noise trigger took into account CPX (Close proximity noise – method) measurements or predicted CPX data as its input.

The main emissions gasses relevant for air quality are NO and NO2. The other type of particulates is Road Dust. No suitable method was found for the latter one. The particulates from the exhaust could be estimated from the state of fuel consumption.

The model used for the fuel consumption was based on the work done in MIRIAM (Models for rolling resistance In Road Infrastructure Asset Management Systems), a related project. Fuel consumption (FC) is a function of driving resistance and engine efficiency. A simplified fuel consumption function was developed in order to express the road surface conditions by a FC index.

The comfort, durability, safety and environment triggers were combined to produce the Combined Condition Indicator (CCI). The value of the triggers can be between 0 and 100, 0 meaning good condition of the road and 100 meaning a need of maintenance.

CCI = w_c*Comfort Trigger + w_D*Durability trigger + w_S*Safety Trigger + w_E*Environment Trigger

Where $w_c + w_D + w_S + w_E = 1$ are values chosen by the Toolbox tool user, depending on the individual road owners' policies.

A spreadsheet tool was developed in Excel that uses the models and combines their output, with user defined weightings, to form the CCI. The index is then used by the spread sheet to identify potential maintenance candidates of a length of 100m (see Figure 7).

The tool divides the whole route provided by the user, into maintenance candidates (or schemes) ready for the user to select for which candidates to carry out cost-benefit analyses.

The aid the selection process, the tool summarizes the schemes created, including the number of lengths created from the scheme and the number of lengths with a minimum suggested treatment of each of the treatment options. The summary also orders the schemes by the number of lengths, with each of the minimum suggested treatment from the most severe (redesign) to the least severe (thin surface) (see Figure 8).

	A	B	C	D	E	F	G	H	I	J	
1	Section	Chainage	Longitudinal Unevenness (IRI) NS	Longitudinal Unevenness (IRI) OS	Longitudinal Unevenness (IRI) ΔIRI	Longitudinal Unevenness (Localised roughness) NS	Longitudinal Unevenness (Localised roughness) OS	Transverse Unevenness (Rut) NS	Transverse Unevenness (Rut) OS	Transverse Unevenness (Rut) Δrut	E R (S
2	0900M6/624	100	11.878			0		4.91	2.7		
3	0900M6/624	200	2.244			0		7.08	7.01		
4	0900M6/624	300	2.176			0		6.21	8.78		
5	0900M6/622	100	11.538			0		7.11	2.31		
6	0900M6/622	200	1.936			0		6.61	1.6		
7	0900M6/622	300	1.366			0		4.38	2.19		
8	0900M6/622	400	2.035			0		2.25	3.08		
9	0900M6/622	500	1.49			0		2.57	3.11		
10	0900M6/622	600	1.747			0		3.39	3.52		
11	0900M6/622	700	1.26			0		4.02	2.84		
12	0900M6/622	800	1.119			0		2.28	2.73		
13	0900M6/622	900	1.299			0		4.62	1.93		
14	0900M6/622	1000	0.924			0		4.54	2.16		
15	0900M6/622	1100	1.241			0		3.66	1.9		
16	0900M6/622	1200	1.207			0		4.12	2.37		
17	0900M6/622	1300	1.727			0		4.35	2.53		
18	0900M6/622	1400	1.435			0		1.98	3.99		
19	0900M6/622	1500	1.288			0		1.9	2.3		
20	0900M6/622	1600	1.86			0		1.52	1.97		
21	0900M6/622	1700	1.179			0		1.93	2.47		
22	0900M6/622	1800	1.445			0		5.08	2.51		
23	0900M6/622	1900	1.542			0		7.57	1.9		
24	0900M6/622	2000	1.36			0		3.79	1.68		
25	0900M6/620	100	12.139			0		3.43	1.69		
26	0900M6/620	200	1.652			0		2.92	1.96		
27	0900M6/620	300	1.346			0		5.87	2.11		
28	0900M6/620	400	1.653			0		4.27	2.07		
29	0900M6/620	500	1.343			0		1.63	2.61		
30	0900M6/620	600	1.102			0		2.32	3.13		
31	0900M6/620	700	1.764			0		3.58	3.56		
32	0900M6/620	800	1.345			0		2.67	3.26		

Data | Summary | Trigger Weighting Parameters | Trigger Thresholds | Treatment Thresholds | Scheme Crea

Figure 7 TOOLBOX Screen shot of part of the data sheet, showing columns for parameter value input

Scheme Number	No. Lengths	No. Redesign	No. Full reconstruction	No. Partial reconstruction	No. Thick overlay	No. Plane off and overlay	No. Thin overlay	No. 100mm Inlay	No. 50mm Inlay	No. Thin surface	No. No Treatment	Average Combined Condition Index
1061	2	0	0	0	0	2	0	0	0	0	0	61
1062	1	0	0	0	0	1	0	0	0	0	0	51
295	1	0	0	0	0	0	0	1	0	0	0	48
294	1	0	0	0	0	0	0	1	0	0	0	43
498	1	0	0	0	0	0	0	0	0	1	0	43
134	1	0	0	0	0	0	0	0	0	1	0	42
974	1	0	0	0	0	0	0	0	0	1	0	39
1148	5	0	0	0	0	0	0	0	0	5	0	39
158	1	0	0	0	0	0	0	0	0	1	0	39
113	1	0	0	0	0	0	0	0	1	0	0	39
622	1	0	0	0	0	0	0	1	0	0	0	39
840	1	0	0	0	0	0	0	0	1	0	0	38
156	1	0	0	0	0	0	0	0	0	1	0	38
499	1	0	0	0	0	0	0	0	0	1	0	37
1063	1	0	0	0	0	0	0	1	0	0	0	37
911	1	0	0	0	0	0	0	0	0	1	0	37
626	1	0	0	0	0	0	0	0	0	1	0	36
385	12	0	0	0	0	0	0	0	0	12	0	36
803	5	0	0	0	0	0	0	0	0	5	0	36
963	1	0	0	0	0	0	0	1	0	0	0	36
685	1	0	0	0	0	0	0	0	0	1	0	36
523	1	0	0	0	0	0	0	0	0	1	0	35
1074	1	0	0	0	0	0	0	0	0	1	0	35
806	2	0	0	0	0	0	0	0	0	2	0	35
836	7	0	0	0	0	0	0	7	0	0	0	35
687	1	1	0	0	0	0	0	0	0	0	0	35
83	1	0	0	0	0	0	0	0	0	1	0	34
624	1	0	0	0	0	0	0	0	0	1	0	34
655	1	0	0	0	0	0	0	0	0	1	0	34
126	1	0	0	0	0	0	0	0	0	1	0	34
1072	2	0	0	0	0	0	0	0	0	2	0	34
690	1	0	0	0	0	0	0	0	0	1	0	34
1007	1	0	0	0	0	0	0	0	0	1	0	34
40	1	0	0	0	0	0	0	0	1	0	0	34
1078	12	0	0	0	0	0	0	0	0	12	0	34
959	1	0	0	0	0	0	0	0	0	1	0	33
693	1	0	0	0	0	0	0	0	0	1	0	33
632	1	0	0	0	0	0	0	0	0	1	0	33
159	1	0	0	0	0	0	0	0	0	1	0	33

Figure 8 TOOLBOX - Summary sheet provided by the tool

In addition, a Life Cycle Cost Analysis was also incorporated in the tool. The aim of the LCCA phase was to optimize maintenance schemes trying to meet different objectives such as budget, LCC, safety, environment and comfort, taking into consideration road users' benefits and deliver road owner life cycle costs.

In order to demonstrate the applicability of the TooBox tool, motorway data from UK, Sweden, Austria and France was used. The outputs were then compared and contrasted with the approaches used by current systems. The results showed that most of the lengths in need of maintenance that were identified by the ToolBox tool could also be identified by maintenance engineers. In addition, the tool also highlights the lengths for which maintenance is needed due to user comfort, environmental factors that are not currently considered by engineers.

Some final recommendations could be given for national road administrations when using the tool:

- The models developed in the projects have known limitations and may need further work;
- The tool needs to be adjusted for each country (i.e. the thresholds, triggers, etc.)
- The availability of the data for all lengths of the network significantly impacts the output of the tool; observations were made in the project on how to deal or missing data;

2.6 InteMat4PMS – Integration of Material-science based Performance Models into Life-cycle Analysis processed in the Frame of PMS

Duration: 01.09.2011 – 31.08.2013

Budget: EUR 305.000

Coordinator: Michael P. Wistuba, TU Braunschweig, Germany

Partners: PMS-Consult, Austria

ViaTec, Switzerland

University of Belgrade, Serbia

The project aimed to develop an advanced procedure to improve performance prediction modelling for asphalt road pavements, by integrating material-science into performance models. Pavement management can be significantly improved by enhancing prediction quality, which strongly depends on the prediction model of pavement performance and the input data.

Objective	Outcome
State of the art and holistic integrated PMS (Pavement Management System) architecture	A review of performance prediction models was performed to gain knowledge on the state of the art of PMS methodologies and tools. An analysis of laboratory assessment methods of structural pavement performance was also done. (see Deliverable 1 [21])
Integration of material based performance functions into PMS	Three empirical performance models (Austrian, German, and HDM-4) were chosen and linked to mechanistic analysis through a calibration procedure. The methodology developed in the project incorporated laboratory material analysis in empirical performance functions (EPF), leading to Laboratory Calibrated EPF. (See Deliverable 2 [22])
Development of a manual for developing PMS based on physical performance functions	The manual is a general framework and includes a comprehensive description of the different steps for the selection of performance models, the selection of an adequate PMS solution and the incorporation of laboratory calibrated empirical performance functions into PMS. (see Deliverable 3 [23])
Demonstration through case studies	Data and asphalt samples from two test road sections from Germany were used to demonstrate the applicability of integration of material-science for pavement management, as well as potential benefits. (see Deliverable 4 [24])
Life-Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA)	The LCA revealed that the estimation of maintenance needs was improved significantly by using the laboratory calibrated models. The results of the LCCA showed that if laboratory calibration is performed, cumulated costs change significantly. (see Deliverable 4)

A literature review was conducted to gain knowledge on the state of the art regarding structural performance prediction analysis used in pavement management systems (PMS), review that resulted in a categorization of performance prediction models. A review of laboratory assessment methods for structural pavement performance was also performed.

Empirical performance prediction models are most commonly used in PMS and apply empirical performance functions (EPF) that result from condition surveys on the road network and do not incorporate structural parameters. Analytical pavement performance is usually based on mechanistic or semi-mechanistic empirical models and includes structural parameters such as permanent deformation, fatigue cracking, road roughness, etc.

Based on the knowledge gained through the literature review, a methodology was developed for connecting data obtained from deterministic empirical performance functions to data obtained from mechanistic analysis. Deterministic EPF describe the future condition of the road by a functional relationship between time variable condition parameters (e.g. rutting, cracking, durability, etc.) and descriptive variables (e.g. age, traffic load, number of loadings, etc.). Linking deterministic EPF to mechanistic analysis was done by means of a calibration procedure, where parameters based on material-science were used as additional input parameters to calibrate key predictive relationships in pavement management systems. The focus was on fatigue related performance.

The calibration procedure was performed for three selected models for surface distress: HDM-4 (Highway Development and Management Model) cracking model, German cracking model and Austrian cracking model, all for asphalt pavements. The calibration process was identical for all cases and was comprised of three steps. Figure 9 shows the process and output of calibrating the empirical performance functions.

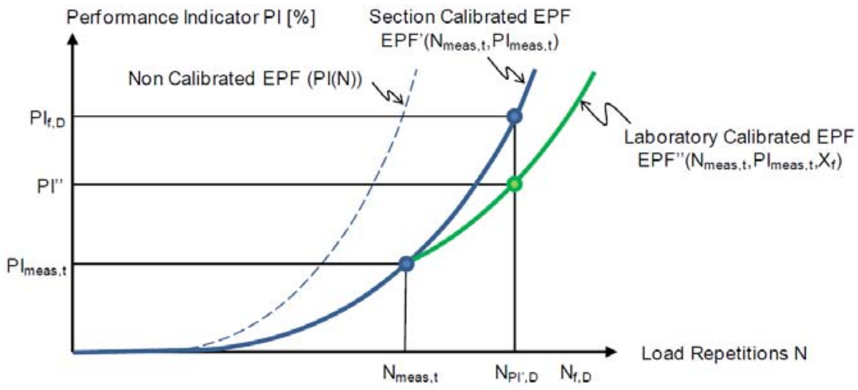

Figure 9 InteMat4PMS - Calibration of the EPF

Where:

$N_{meas,t}$ – number of load repetitions the pavement has already been subjected to until the time t

$PI_{meas,t}$ – performance indicator of the pavement condition at the time t

$N_{f,D}$ – number of load repetitions link to a specific amount of damage D

X_f – scaling factor

PI' – performance indicator resulted from section based analysis

Section based calibration of the selected EPF

The adaptation of the empirical performance functions was done by using section specific information. The number of traffic load repetitions is the key parameter that describes the structural pavement deterioration in function of time. As a result of the section-based analysis, a performance indicator PI' was found and the Section Calibrated EPF was obtained.

Laboratory analysis

Laboratory tests were done on material samples by performing cyclic material tests. The output from material testing was used for pavement modelling and for finding a mechanistic performance function.

Integrating laboratory data into EPF

The results of the laboratory analysis were then used to improve the Section Calibrated EPF (EPF'). Therefore a new function was obtained, called Laboratory Calibrated EPF (EPF") (see Figure 9). As performance analysis done in a laboratory is not equal to an in-field pavement performance evaluation, a scaling factor was used to account for the discrepancy.

The methodology developed was then applied on real data in order to demonstrate the applicability and the potential benefits for pavement management. The inventory data, road condition data and laboratory data were inputted in the commercial software dTIMS CT™. The effects of laboratory calibration and PMS adaptation were evaluated through a Life-Cycle-Analysis (LCA).

Data was taken from two test road sections located in Germany. Laboratory testing was done on asphalt mix samples for characterization of stiffness and fatigue properties of the base course layer. A shift factor was applied to cover the differences from laboratory data to real pavement performance. Based on the laboratory data, a mechanistic pavement design model was developed and used to estimate the remaining life of the pavement. For the empirical performance functions, the three different performance prediction models were comparatively implemented, namely the Austrian, German and HDM-4 (2 options) models and then calibrated for the two test sections.

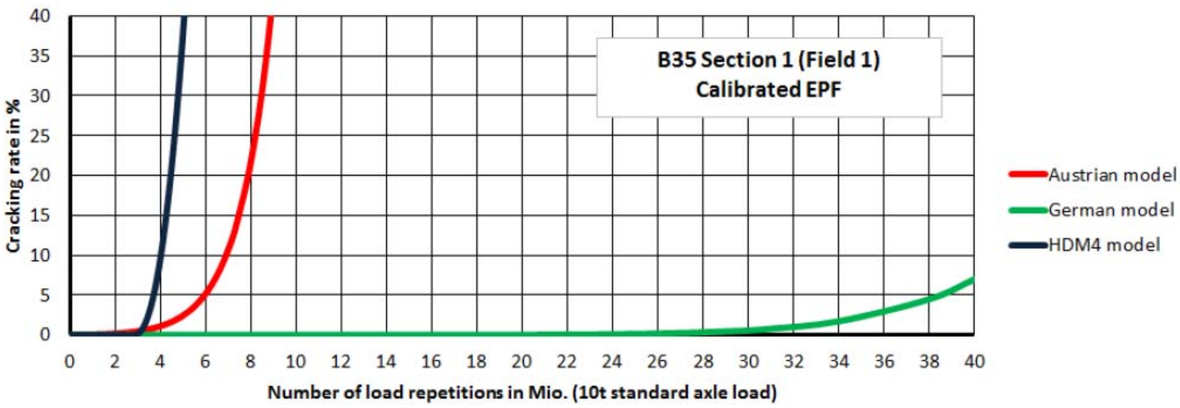

Figure 10 InteMat4PMS - Test section 1: Section calibrated EPF, considering Austrian, German and HDM-4 models

Figure 10 shows a comparison between Section Calibrated EPF obtained from the different models. It can be observed that the choice of the performance model significantly influences the results of the PMS analysis. By incorporating the laboratory data of the two sections, the Laboratory Calibrated functions were obtained. In Figure 11 the same comparison can be seen, but of the Laboratory Calibrated EPF. The results of the different models are all in the same range.

To qualitatively evaluate the effects of using Laboratory Calibrated EPF within PMS analysis, Life-Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) were performed. The Life Cycle analysis revealed that the estimation of maintenance needs was improved significantly by using the laboratory calibrated models.

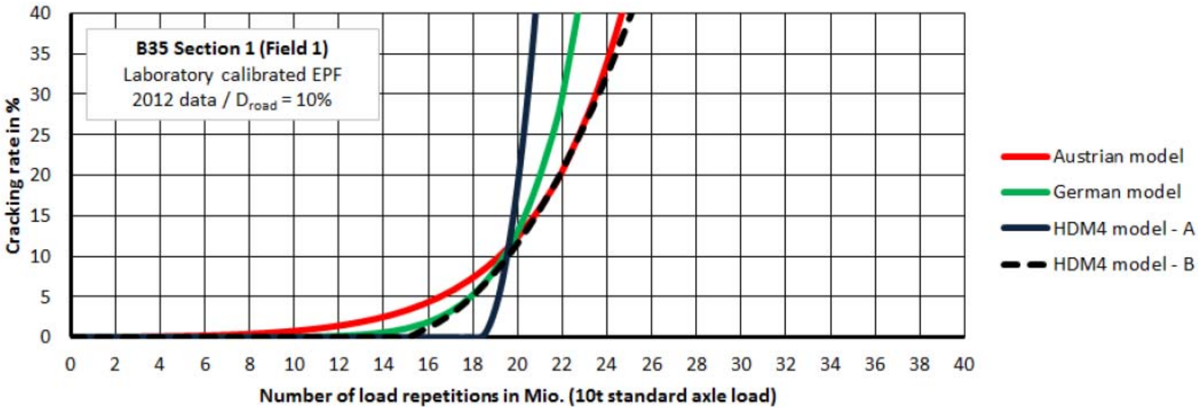

Figure 11 InteMat4PMS – Laboratory Calibrated EPF for Test Section 1, 2012 data

The Life Cycle Cost Analysis was performed for 10 different scenarios for each test section, by taking into account pavement design, construction, maintenance and time (user) costs. The LCCA was limited to crack modelling. The results showed that if laboratory calibration is performed, cumulated costs change significantly. Additionally, the laboratory based calibration led to identical total costs for all three applied models (Austrian, German and HDM-4) at the end of the assessment period, which means that the PMS analysis became less sensitive to the general performance model applied.

The methodology developed in the project can be applied to further distress mechanisms in subsequent research. Especially the assessment of permanent deformation (rutting) seems to be an adequate candidate for further development and fulfils most of the preconditions from both the laboratory and PMS points of view.

The improvement of pavement management systems on project level by using material specific input parameters will extend and enhance the field of PMS application. For LCA and LCCA, laboratory calibration of EPF can improve the prediction accuracy for future maintenance strategies, i.e. type of maintenance treatment, year of maintenance, etc. This will help road mangers to perform budgetary planning more efficiently.

3 Outcomes of the ENR Design Final Conference

At the conclusion of the programme, a two day conference was organised, to present the results and overall conclusions of the six projects. The conference was held on January 23rd-24th in Vienna, Austria and was hosted by the AIT Austrian Institute of Technology. Three parallel group discussions (Safety, Maintenance and Materials) on the six projects were carried out, with focus on three main topics:

- Highlights: What project outcomes are considered the most important?
- Implementation: How can the project outputs be implemented in NRA activities? What are the benefits and obstacles for implementation?
- Open questions: What questions remain to be solved?

The first group discussion – **Maintenance** – focused on the projects **InteMat4PMS**, **MOBI-ROMA** and **TOOLBOX** and was moderated by Mr. Roland Spielhofer from the AIT Austrian Institute of Technology.

The second group discussion – **Materials** – focused on **InteMat4PMS**, **RECYPMA** and **POTHOLE** and was moderated by Mr. Manfred Haider from the AIT Austrian Institute of Technology.

The third group discussion – **Safety** – focused on the **STARs** project, and it was moderated by Mr. Philippe Nitsche from the AIT Austrian Institute of Technology.

3.1 STARs

The aim of the STARs was to enable maintenance contract authorities across Europe to set appropriate and effective contractual limits for the impacts of road maintenance and construction works on traffic.

3.1.1 Highlights and remarks

The discussion on STARs highlighted the ability of combining three different risk areas for a harmonised evaluation:

- The combination of road user safety, road worker safety and network performance is an innovation, as for each, there are different measures and different safety standards;
- The integration of road worker safety is unique, as it has not been done in previous projects;
- The tool is extremely flexible and adjustable to new data for future calibration and improvements;
- The equations used in the tool can also be considered highlights, as well as the interrelation between them;
- The categorisation of road works at a European level is also an important project output and can be developed further for a possible harmonisation of road works regulations.

3.1.2 Implementation steps

In terms of implementation, the versatility of the tool was discussed:

- The tool is “proof of concept” and requires further development, to address more specific needs for the users;
- Further calibration should be done by using more data and running more case studies to validate the equations;
- The tool could be used by NRAs in their guidance and design, but it could also be used for road works regulations, i.e. to justify choosing a certain method;
- A possible optimisation of the tool could be to add a cost module, for the user to see the costs associated with each alternative presented by the tool;
- In terms of customisation or generalisation of the tool, the option of customising the tool is considered superior;
- As a next step, the tool must be tested on a national level, i.e. by presenting it and adapting it according to the needs of road administrations.

3.1.3 Open questions

The following open questions remain:

- How to find more data for further calibration and improvement of the tool?
- Who is responsible for the future development of the tool, including the development of a more user-friendly graphical user interface?

3.2 POTHOLE

The main objective of POTHOLE was to address the need of road agencies for durable construction and maintenance methods for damage repairs, which occur after hard winters (due to repeated frost-thaw cycles).

3.2.1 Highlights and remarks

The main highlight of the project was considered to be the developed guidelines:

- The presence of potholes always indicate the beginning of a problem and their repair is reliable just for a limited amount of time (maximum 5 years);
- The use of recycled materials is not optimum, while the use of concrete, although not perfect, is considered viable;
- The costs associated with the management of pothole repairs are much lower than the costs of reduced network availability;
- The guidelines present an extensive overview of the available materials and repair techniques for potholes, that give national road administrations an insight in what are the best solutions for their specific needs;
- An evaluation of the reliability of the techniques and materials was also performed.

3.2.2 Implementation steps

Regarding implementation, the focus is on dissemination of the project results:

- The guidelines offer support to NRAs when deciding which combination of materials and procedures to choose according to the actual need of durability;
- The next step is to present the developed guidelines to national road administrations.

3.2.3 Open questions

Open questions remain regarding:

- How to disseminate the guideline across CEDR countries?
- Who should be responsible for updating the guideline in the future, as more information and data becomes available?

3.3 RECYPMA

The aim of the project was to investigate the possibilities for recycling polymer modified asphalt from surface layers into new high quality surface layers using hot mix recycling.

3.3.1 Highlights and remarks

The discussion on RECYPMA focused on the potential benefits of recycling:

- Extracted polymer binders from reclaimed material are still active and can be reused;
- A mix of 40% reclaimed material with 60% new material gives a performance which is comparable to one with 100% new material;
- The methodology developed in the project is not designed for practice, but it does show the possibilities and benefits of using recycled material towards a more effective pavement management system;
- The project was limited to laboratory studies and it was known what type of material to extract from the reclaimed asphalt;
- There is a lack of data concerning how to deal with unknown reclaimed material and therefore more case studies are needed.

3.3.2 Implementation steps

In terms of implementation, more pilot projects would be needed before network application:

- A quick and reliable test to evaluate the key parameters of reclaimed material must be developed and established, in order to identify what type of material to extract and how to best reuse it;
- For network application, mixing different types of reclaimed asphalt should be avoided, in order to keep the reclaimed material clean and manageable;
- Separation of reclaimed asphalt for further use should also be considered;
- An analysis of the costs and benefits should be performed when considering

implementation at a network level.

3.3.3 Open questions

Open questions remain regarding:

- How is the performance of various mixes in practice?
- What is the best material to extract from reclaimed material?

3.4 MOBI-ROMA

The project's key objectives were to develop, test and evaluate improved affordable and moderate-cost road condition and performance assessment techniques, which offer new effective tools for monitoring and assessing maintenance needs across Europe.

3.4.1 Highlights and remarks

The main remarks on the MOBI-ROMA project emphasised the applicability of the developed tool:

- The intuitive map visualisation of data is considered as important as the data itself, especially because the tool's outputs is also presented to non-experts,
- The project addresses an important issue in Nordic countries, namely the fact that there is no monitoring data available for gravel roads; the quality of maintenance decisions is currently limited due to lack of data;
- The lack of monitoring data is also considered an issue for low-volume roads in non-Scandinavian countries;
- The tool is working and available on the project's website: www.MobiRoma.eu.

3.4.2 Implementation steps

The successful implementation of floating car technology depends on multiple factors:

- The FCD methodology should be considered a complement and not a substitute to current monitoring methods;
- Data standards should be developed at European and international level, in order to have the possibility of mixing data from different types of vehicles and mobile measuring equipment;
- There is already a follow-up project running in Sweden, making use of 50 postal cars and collecting data, using FCD technology.

3.4.3 Open questions

Open questions remain regarding:

- What is the level of data quality needed for successful implementation of FCD technology?

- Will vehicle fleets be equipped with data collection systems in the future?
- What is the best method to deal with the privacy issues that could arise?
- Can FCD replace accurate IRI data, for identifying sections in need of maintenance?

3.5 TOOLBOX

The aim of the project was to advance the development and implementation of practical strategies and tools to assist road authorities in selecting maintenance candidate in their road networks.

3.5.1 Highlights and remarks

The observations on TOOLBOX underscored the importance of having the user in mind and taking factors such as safety and environment into account:

- The tool is working and available for use;
- The end user can relate much better to a comfort indicator value, rather than a value for the International Roughness Index (IRI);
- The models developed for safety and fuel consumption impacts are innovative and give the road operator more options when selecting maintenance candidates;
- The fuel consumption model is considered especially important, as it shows how different maintenance decisions can influence CO_2 emissions.

3.5.2 Implementation steps

Regarding implementation, the project's results open up possibilities for future developments in pavement management systems:

- The tool is able to identify road lengths in need of maintenance and make a prioritisation of treatments needs;
- Additional data could improve the developed models and further calibrate the tool to address the specific needs of a national road administration;
- CO_2 emissions are considered to become increasingly important in the context of the European Union and reduction of greenhouse gas emissions; therefore, there is a need for data on road maintenance's contribution to greenhouse gas emissions;
- The fuel consumption model developed in the project could be easily integrated into current PMS applications.

3.5.3 Open questions

Open questions remain regarding:

- What are the best models to use, since different countries use different models?
- How to achieve harmonisation across Europe, for the best possible outputs in the tool?

3.6 InteMat4PMS

The project aimed to develop an advanced procedure to improve performance prediction modelling for asphalt road pavements, by integrating material-science into performance models.

3.6.1 Highlights and remarks

The InteMat4PMS project was discussed both in the contexts of materials and maintenance. Some of the highlights include:

- The prediction quality can be highly improved by combining empiric deterioration models with material models;
- The methodology developed in the tool – the calibration – can be considered a major highlight, as it showed that three very different models (Austrian PMS, German PMS and HDM-4) could be harmonised using the proper calibration approach;
- The prediction functions were also improved by having a good cooperation between people from different disciplines – material science and asset management.

3.6.2 Implementation steps

In terms of implementation, some relevant factors need to be taken into consideration:

- Further research still needs to be done, as a laboratory approach gives too little information to simulate long term effects;
- Assumptions are still necessary to find the link between laboratory tests and field usage, as “end of life” on road is still a matter of expert decision;
- For the implementation of the project methodology, a structural model for prediction of residual life would be needed;
- Also, a classification of road sections with comparable materials/structures at a network level would help keep costs at an optimum level;
- The availability of data at a network level is a limiting factor for applying the methodology on other parameters, such as resistance to deformation, low temperature (cracking) and others. Material testing is still not a common procedure in road construction projects.

3.6.3 Open questions

Open questions remain regarding:

- How can laboratory testing be further improved to produce more accurate/realistic results?
- How to transfer the results of the laboratory tests to field usage?

4 Conclusions and recommendations

ERA-NET ROAD II aimed to strengthen the European Research Area in road research by coordinating national and regional road research programmes and policies. The overall aim of the trans-national joint research programme **ENR 2011 "Design – Rapid and durable Maintenance Methods and Techniques"** was to improve road conditions for the short- and long-term.

There is significant potential for improving the traditional road maintenance approaches through application of better material technologies, effective, safe, environmentally friendly methods and standards for road maintenance, in order to prolong the service life of road and other road elements. The objectives of the programme were developed following a series of workshops involving specialists from each of the partner road authorities. It was recognised that the traditional approach without pan-European cooperation, often resulted in duplication of research. The research programme sought to address the problem into an optimised management framework.

The ENR Design initiated projects focused on concepts such as safely optimising road network availability during maintenance (STARs), durable construction and maintenance methods (POTHOLE, MOBI-ROMA) and strategies for reducing maintenance costs (RECYPMA, InteMat4PMS, TOOLBOX).

The tools, methodologies and models developed in the projects will provide road administrations with extensive knowledge on:

- How to set appropriate and effective contractual limits for an efficient management of road works, taking into account road user safety, road worker safety and network performance;
- What are the most durable construction and maintenance methods for damage repairs of potholes, which occur after hard winters;
- What are the requirements and benefits of using recycled polymer modified asphalt into new high quality surface layers, on the road network;
- How to monitor and assess road maintenance needs across Europe, using Floating Car Data methodology;
- How to optimally identify and select road lengths maintenance candidates, taking into account durability, safety, comfort and the environment;
- How to improve performance prediction modelling for asphalt road pavements, by integrating material-science into prediction models, towards a more efficient pavement management system.

Benefits of the Programme to NRA stakeholders

The tool developed in **STARs** has the ability of combining road worker safety, road user safety and network performance, for a harmonised evaluation of management at road works. A major advantage of the tool is its flexibility and adjustability to new data. As a next step, the tool must be tested at national level and Mr. Xavier Cocu from BRRC has expressed his intention of presenting the tool to the Flemish Road Authorities. This would lead to customisation of the tool to the needs of a specific user, for an optimised use.

The **POTHOLE** guidelines can offer support to national road administrations when deciding which combination of materials and procedures to choose according to their specific needs of durability. As the presence of potholes constitutes a problem at a European level, having an extensive overview of the available materials and repair techniques, can lead to a more efficient and optimised methodology of dealing with damage repairs that occur after hard winters.

Although the applicability of the **RECYPMA** results cannot be seen immediately, the developed methodology showed the possibilities and benefits of using recycled material towards a more efficient pavement management system. It is the recommendation of the project partners that more pilot projects to be organised for testing and validating the approach. Applying this methodology to network level could lead to significant economic benefits.

The tool developed in **MOBI-ROMA** can be used as it is and it is available on the project's website (MobiRoma.eu). The project addressed an important issue in Nordic countries, namely the lack of monitoring data for gravel roads. Therefore, the project results could benefit the road administrations where this is a problem. There is already a follow-up project running in Sweden, making use of 50 postal cars for data collection, proving that Floating Car Data technology has the potential of being a reliable complement to current road monitoring techniques.

TOOLBOX showed how road maintenance candidates can be identified and selected with a practical tool that takes into account high level indicators such as comfort and environment. As CO_2 emissions are becoming increasingly important in the context of the European Union and the reduction of greenhouse gas emissions (GHG), a benchmark model for the evaluation of road maintenance's contribution to GHG could bring significant benefits to national road administrations.

InteMat4PMS revealed that pavement management systems can be greatly optimised by integrating material science into prediction modelling of pavement roads, thus improving the prediction accuracy for future maintenance strategies. The methodology developed in the project can be used in subsequent research for studying other distress mechanisms such as resistance to deformation and others.

As the joint research programme comes to an end, some general recommendations can be given:

- There is significant potential in optimising and improving the current pavement management systems, as the Design programme has shown;
- Further research work is needed to enhance and further develop the outcomes of the projects;
- The results (tools, models, guidelines) should be disseminated across CEDR member countries;
- Data availability is still an issue and more interaction between the projects would be valuable and would help complement and strengthen the results;

The **ERA-NET ROAD** concept encourages the exchange of knowledge between National Road Administrations in Europe and gives them the opportunity to improve the quality of European roads, while reducing costs. Through this programme, tools and procedures were developed on how to cooperate internationally on various topics and projects. The success factors were trust (between the partners), understand (what are the relevant topics) and commit (through funding and dedication). The joint programme ENR "Design – Rapid and durable Maintenance Methods and Techniques" has been a success, as it included a number of European countries as project partners and addressed the multiple issues of pavement management systems into an integrated framework.

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Abbreviations

ABS	Anti-lock braking system
AIT	Austrian Institute of Technology
ALERTINFRA	Detection of dangerous road configurations
BiFi	Bearing information through vehicle intelligence
BRRC	Belgian Road Research Centre
CAN-bus	Controlled Area Network
CCI	Combined Condition Index
CETE	Centre of Technical studies and Equipment
CMA	Cold Mix Asphalt
CPX	Close Proximity Noise
DRI	Danish Road Directorate
DSR	Dynamic Shear Rheometer
EN	European Standard
ENR	Era Net
ERA-NET	European Research Area Network
ESP	Electronic stability program
FC	Fuel consumption
FCD	Floating Car Data
FEHRL	Forum of European National Highway Research Laboratories
FTIR	Fourier Transform Infrared spectroscopy
GPC	Gel Permeation Chromatography
GPS	Global Positioning System
GPRS	General Packet Radio Service
GUI	Graphical User Interface
HDM-4	Highway Development and Management Model
HMA	Hot Mix Asphalt
IRI	International Roughness Index
Intemat4PMS	Integration of material-science based performance models into life-cycle-analysis processed in the frame of pavement management systems
INTRO	Intelligent Roads
KIT	Karlsruhe Institute of Technology
LCA	Life Cycle Analysis
LCCA	Life Cycle Cost Analysis
LCCBA	Life Cycle Cost Benefit Analysis

MARVIN	Modell zur Abschätzung des Risikopotenzials von Verkehrsinfrastruktur
MIRIAM	Models for rolling resistance in Road Infrastructure Asset Management Systems
MOBI-ROMA	Mobile Observation Methods for Road Maintenance Assessments
MPD	Mean Profile Depth
NRA	National Road Administration
PGB	Paving Grade Binder
POTHOLE	Durable Pothole Repairs
PMB	Polymer Modified Binder
PMS	Pavement Management Systems
RA	Reclaimed Asphalt
RECYPMA	Possibilities for high quality Recycling of Polymer Modified Asphalt
SBS-PMB	Styrene-Butadiene-Styrene Polymer Modified Binder
SRIS	Slippery Road Information System
STARs	Scoring Traffic at Road Works
TNO	The Netherlands Organization for Applied Scientific Research
TOOLBOX	A method to select maintenance candidates
TRL	Transport Research Laboratory
UK	United Kingdom
UNIZA	University of Zilina
UT	University of Twente
VTI	The Swedish Road National Road and Transport Institute
ZAG	The Slovenian National Building and Civil Engineering Institute