ASCAM

***A**sset Service **C**ondition **A**ssessment **M**ethodology*

Deliverable No.2

Inventory Pavement Management practices

Final report

November, 2012

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This project was initiated by **ERA-NET ROAD**.

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APPENDIX 1

Data on the technical parameters monitored in European countries

1 Introduction

This introduction is split into a general introduction which applies to all reports and a specific one for each work package report.

1.1 General Introduction to the ASCAM Reports

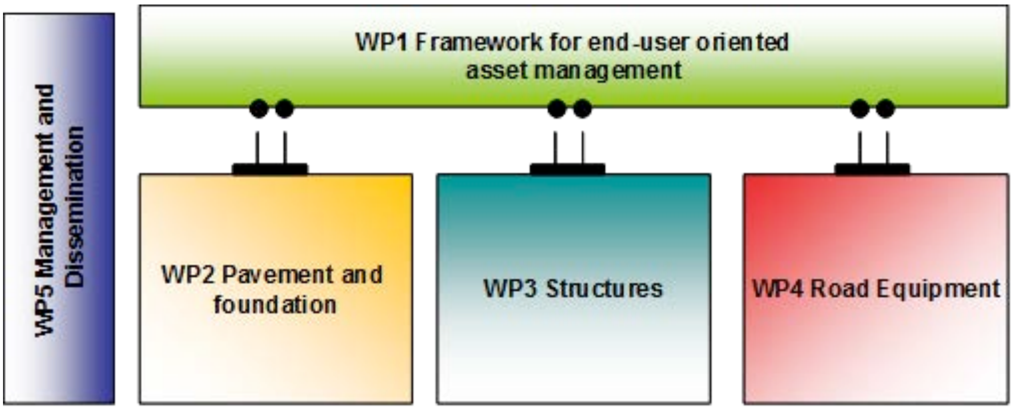
The aim of the ERANET ROAD program "Effective asset management meeting future challenges" is to improve the management of the European road network, resulting in an improvement of the performance of the network. One of the topics within this program is the development of a framework for optimized asset management [ref: Effective asset management meeting future challenges, Description of Research Needs (DoRN), version 3.3, January 2010].

Maintenance managers on all levels are faced with the same dilemma. On the one hand, they are given "end-user services levels" (objectives like reliability of traffic time, traffic safety, sustainable maintenance program), and on the other hand, they have their assets, the asset condition and a (dynamic) portfolio of measures which can be taken to ascertain the "end-user service levels". The dilemma arises through the need for an optimal trade-off between available budget and required budget for ascertaining the service levels.

ASCAM focuses on a framework for optimized asset management and relates asset condition prediction to measures and network value (end user service levels). It creates a framework to connect existing asset management practices into a holistic, integrated cross asset, pro-active approach. It relates technical to societal issues, like pavement degradation or failures in the "dynamic traffic management systems" to end-user service levels such as efficient traffic flow, safety, reliability of travel time, noise pollution or environmental issues. It links micro, meso and macro levels in asset management and the aims and objectives on the different levels, combining existing knowledge, tools and practices. The framework will enable policy makers, maintenance managers and their specialists to communicate on different levels and to overcome the boundaries between fields of knowledge.

In this study, a proof of concept of the framework is developed in which existing knowledge, tools and practices are implemented and linked to end user service levels.

The following approach was taken within this project in order to develop and deliver the proof-of-concept of this framework: Five work packages were established. In one of them (WP5) all management and dissemination activities were performed. In three other work packages (WP2, 3 and 4) an inventory of existing asset management practices in the EU was made, divided according to asset type (pavement, structures and road equipment, respectively). The results were intended and used in the last work package (WP1) for assessing the feasibility and appropriateness of the framework which was developed in this work package. Also in work package 1, a proof-of-concept in the form of a numerical implementation was made. With this demonstrator, the effects and possibilities of applying the framework on asset management was shown. The project layout is given in the figure below.



Reports

The work done is documented in 5 reports, a power point presentation and a demonstrator with a user guide. The 5 reports are:

- Framework principles
- Inventory Pavement Management practices
- Inventory Bridge Management practices
- Inventory Road Equipment Management practices
- End report ASCAM

The inventories performed in work packages 2, 3 and 4 deliver a representative view on asset management in Europe, including its diversity over the different countries. Such an inventory is efficient and effective for assessing the feasibility and appropriateness of the framework and to deliver the proof-of-concept. They are not intended and do not deliver a full comprehensive inventory of all available asset management systems. Therefore it is possible that NRA's will miss certain information or systems.

The terminology used in asset management is not consistent across Europe. This is due to the diversity in e.g. approach, level of implementation, etc. In our reports, no attempt is made to identify these discrepancies. This was by no means the purpose of this project. However, this necessarily compromises the readability of these reports.

In the reports of WP2, 3 and 4 an attempt was made to develop the existing asset management system a step further towards the framework principles, by developing relations between asset conditions and EUSL. This is an innovative step, which required temporarily abandoning conventional definitions of sometimes well-established concepts as, for instance, safety.

This report concerns "Inventory Pavement Management practices".

1.2 Introduction to this report

A road network, like any major asset, has a number of individual and distinct components. From an asset management point of view, the components of greatest interest are:

- components that are key contributors to performance (to satisfy stakeholder needs),
- components that are most prone to deterioration or need ongoing management,
- components that are the most expensive (in terms of life cycle costs).

Therefore, for asset management of a road network, the components of greatest interest include

- sections of road pavements (the road surfacing and structural layers that support the traffic loading),
- structures (bridges, retaining structures,),
- road furniture (traffic control equipment - such as signals, roadside intelligent transport system installations etc.),
- road reserves (road formations, cuttings and embankments),
- drainage (culverts)

The main objective of this work package is to gather data on existing management systems for pavements. These systems are evaluated with regard to end-user service levels and the asset condition evaluation concepts. Pavement management systems and their implementation differ throughout the European member states. These systems are constantly being improved with the aim of developing an advanced, more effective approach.

The state-of-the art of pavement management frameworks in different countries (partners within the ASCAM project) was studied on a technical level and the benefits of different management strategies regarding end-user service levels were identified.

The state-of-the-art of pavement monitoring currently employed in practice is also identified within the ASCAM project. The members of the WP2 are.

Table 1 The members of WP2

Country	Institute	Experts	telephone	e-mail
Slovenia	ZAG	Mojca Ravnikar Turk Darko Kokot	+386-41-770-542 +386-31-617-316	mojca.turk@zag.si darko.kokot@zag.si
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Sweden	VTI	Robert Karlsson	+46-70 881 24 09	robert.karlsson@vti.se
Belgium	BBRC	Christophe Casse Carl Van Geem	+32 (0)10 23 65 41	c.casse@brrc.be c.vangeem@brrc.be
Croatia	IGH	Jelena Bleiziffer	+385 99 7046 888	jelena.bleiziffer@igh.hr

1.2.1 Definitions

The following explanations are given in order to clarify the meaning of the terminology used in this report.

ASCAM framework: a tool to predict the cost and effect of maintenance strategies for a network of roads over a time span of years. The principles of the framework are implemented in an ASCAM demonstrator for a hypothetical information set. It is meant to be the "proof of principle".

End user service level (EUSL): A quality-related performance criterion for road pavement condition, such as safety, cost, environmental impact.

Asset: A physical component of a road system or network. An asset is considered worthy of separate identification if it delivers services or benefits to the community which are of sufficient current or future value to warrant control and management on an individual basis. Typical assets include sections of road, individual bridges, culverts, sets of traffic signals, signs, road furniture, road reserves, etc.

Asset management: A systematic process of effectively maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing the tools to facilitate a more organised and flexible approach to making decisions necessary to achieve the public's expectations. (source: OECD and PIARC 1999)

Single Performance Indicator: A technical characteristic or an index that indicates the condition of an asset.

Combined Performance Indicator: A number (dimensional or dimensionless) related to two or more technical characteristics.

1.2.2 Description of work

The work with regards to work package 2 was split into the two following tasks which are described below.

1.1.1.1 Inventory of existing management systems

The main goal of the task 2.1. was to evaluate the existing pavement management frameworks used in ASCAM and ERA-NET ROAD partner countries. The available data was evaluated with regard to application types and end-user service levels, measurements and reporting (for data collection with questionnaires, see 1.2.2.2).

1.2.2.1 Principles and methods for pavement condition assessment

Within the task 2.2 analyses and elaboration on the results of task 2.1 have been performed to enable input to the proof-of-concept framework which relates infrastructural (cross-asset) measures and their costs to the end user service levels.

Based on the recommendations of literature and experience from stakeholders, the current practice of pavements monitoring requirements is described. Building stones for the framework are the relations between the measures and the (improvement of the) asset condition and the relations between asset condition and end user service levels. A method to objectively compare different end user service level is part of the results of the project.

Therefore the main information that was gathered with the help of a questionnaire is the relationship between performance indicators and degradation of roads, measures and improvement of road condition and the relations between pavement condition and end user service levels in different countries. This should provide an inventory of existing practices, tools, and strategies in NRAs for

- key performance indicators (combined parameters reflecting management goals),
- degradation models used for roads in existing practices,
- indicators currently used for planning maintenance measures,
- inventory of existing measures,
- costs of measures.

1.2.2.2 Questionnaire

A questionnaire on pavement management was prepared, enquiring about the implementation of monitoring, the relationship between monitoring results and pavement performance as well as planning of improvements. The questionnaire covered an inventory of existing measures which affect the pavement condition and efficiency of maintenance activities. The questionnaire also covered the inventory of existing knowledge on predictions of pavement condition.

The quite extensive questionnaires were distributed thru ERA-NET ROAD experts to the national road agencies (NRA). The aim was to find out what performance indicators the operators employ to measure the conditions of the pavements, what interventions they use, and what the benefits of different management strategies are regarding end-user service levels. Feedback to the questionnaire was received from ASCAM members Austria, Croatia, Slovenia, Sweden and Belgium. Overall, the answers together with a literature review delivered an inventory of existing practices amongst NRAs for

- key performance indicators (KPI), combined/single parameters,
- degradation models for KPIs,
- indicators currently used for planning maintenance measures,
- list of existing measures,
- costs of these measures.

2 Task 2.1: Inventory of existing management systems

2.1 Introduction

Road monitoring includes measurements of technical parameters of the pavement. All European countries implement monitoring techniques i.e. measurements of Performance Indicators to provide input data for their maintenance systems. Performance Indicators are physical characteristics of the road pavement that indicate its condition. They can be expressed in the form of a technical parameter (dimensional) or in the form of an index (dimensionless). The following Performance Indicators (PI) can potentially be monitored on pavements:

- Transverse evenness (rutting)
- Longitudinal evenness
- Friction (skid resistance)
- Surface defects - cracking
- Macro-texture
- Bearing capacity
- Environmental – noise, air pollution

2.2 Literature review

2.2.1 COST Action 354 “Performance Indicators for Road Pavements”

A thorough review of the technical parameters used in Europe was done within the COST Action 354 “Performance Indicators for Road Pavements”. An extensive database on the technical parameters was formed in 2008. Some of the data on the technical parameters monitored in European countries are given in Appendix 1. The data are taken from the COST 354 report. As for the ASCAM partner countries, the parameters monitored are the same in 2011.

2.2.2 SPENS – Pavement Performance Indicators

A three year EU Framework programme 6 project SPENS – Sustainable Pavements for European New Member States was finished in 2009. The objective of the research project was to develop appropriate tools and procedures for the rapid and cost-effective rehabilitation and maintenance of roads. The overall objective was to search for materials and technologies for road pavement construction and rehabilitation that would behave satisfactorily, have an acceptable environmental impact and be cost-effective.

Within the project data on the implementation of monitoring techniques were gathered. In the deliverable D11 of the SPENS project ‘Guidelines for non-destructive pavement measuring techniques’ were prepared. Non-destructive pavement measuring techniques have several advantages e.g. tests are performed in-situ and are normally done in fluent traffic and do not hindrance the traffic flow. Test are suitable for monitoring on a network level and due to high speed measurements sections of several kilometres lengths can be measured per day.

Pavements are not weakened. A possible disadvantage of high speed measurements is a lower precision compared to static or quasi-static measurements. This disadvantage is becoming smaller as sensor technique improves.

On a network level, the main purpose of non-destructive pavement measurement techniques is to provide input data for pavement management systems. The measured raw data is usually aggregated to 20, 50 or 100 m long sections. Some pavement management systems apply a homogenization algorithm on these data to get longer section lengths.

For the acquisition of reliable results of pavement measurement techniques quality assurance and trained and experienced personnel are of vital importance. Measurement procedures should be defined in work instructions. These should include regulations for allowed temperature range, season, and surface conditions.

Reference sections for harmonisation exercises and routine quality checks and calibration should be visited regularly.

2.2.2.1 Transverse evenness measurements (Rut depth)

There are two commonly used transverse evenness measuring techniques: 2 m, 3 m or 4 m Straight Edge which represents static means of measurements and of high speed profilometer laser technique which can function separately or simultaneously with other road condition survey systems (ARAN, ARGUS etc.) -Table 2.

Table 2 Rut depth measuring devices in some EU countries

Country	Measuring Device
Austria	Profilometer, 4-m Straight Edge
Bulgaria	Dipstick Road Profiler, 4-m Straight Edge
Czech Republic	2 m Straight Edge, ARAN-Automatic Road Analyzer, ARGUS-Automatic Road Condition Graduating Unit System
Hungary	3 m Straight Edge (occasionally) , RST Road Survey Tester
Poland	Profilograph
Slovakia	Profilograph GE
Slovenia	4 m Straight Edge
Sweden	3.2 m Wire method, Laser RST and Profilograph

2.2.2.2 Longitudinal evenness measurements

For longitudinal evenness, different kinds of profilometers are used. These are usually contactless, laser sensor and/or accelerometer based devices. The 4 m straight edge and the profilograph are also commonly used (Table 3).

Table 3 Longitudinal evenness measuring devices in some EU countries

Country	Measuring Device
Austria	Profilometer, 4 m Straight Edge

Bulgaria	Profilograph, 4 m Straight Edge, APL
Czech Republic	4 m Straight Edge, ARAN, ARGUS
Hungary	Profilograph, 4 m Straight Edge (occasionally), RST Road Survey Tester
Poland	Profilograph, APL
Slovakia	Profilograph GE
Slovenia	Profilometer, 4 m Straight Edge
Sweden	Laser RST and Profilograph

The straight edge as static and the Profilograph as quasi-static measurement device are widely used for acceptance tests on newly built roads throughout Europe. In general, evenness defects of longer wavelengths cannot be detected by these devices. Wavelengths up to 60-100 meter can be measured with enough accuracy for unevenness assessment. The high speed measurement devices use laser sensors and/or accelerometers to record a true profile. From this profile, different indices can be calculated, with the IRI as the most popular among them. Spectral analysis can also be done only on a profile of a certain length.

Harmonisation of the results of these tests can rely on the use of a reference device that makes the judgement of how good a device operates rather easy. VTI Primal, ARRB Walking Profile and FACE Rolling Dipstick are well established reference devices.

For the accreditation for network monitoring, not only the measurement device itself should be investigated. Equally important is the computation of the indices from the measurement results. For IRI there exists a reference implementation by UMTRI (accessed in 2011 http://www.umtri.umich.edu/content/IRIMain.f).

Figure 1 Longitudinal evenness – VTI primal, VTI, Sweden (SPENS 2008)

2.2.2.3 Skid resistance measurements

A large variety of methods and devices are used for skid resistance measurements. In many countries, the British Pendulum (SRT) test is used. It is at the moment the only internationally standardized procedure described in EN 13036-4:2011Road and airfield surface characteristics - Test methods - Part 4: Method for measurement of slip/skid resistance of a surface: The pendulum test. This test is static and is not suitable for monitoring on a network level.

Table 4 Skid resistance measuring devices in some EU countries

Country	Measuring Device
Austria	RoadSTAR, Griptester, British Pendulum (SRT)
Bulgaria	Skid Resistance Tester (SRT)
Czech Republic	SCRIM, TRT
Hungary	SCRIM, Skid Resistance Tester (SRT)
Poland	Skid Resistance Tester (SRT)
Slovakia	Skiddometer BV 11
Slovenia	SCRIM, British Pendulum (SRT)
Sweden	Saab friction Tester, Longitudinal friction coefficient

Apart from different high-speed measurement principles, there are some general guidelines for skid resistance measurements: measurements should be done in the wheel track, not between the wheel tracks. The nearside wheel track should be chosen, which is the right wheel track in countries with right-hand traffic. The reason for this is that the wear is much heavier in the wheel track than in between. Speed correction and correction of seasonal and temperature influences may be necessary.

Reasonable intervals for network monitoring are 3 to 5 years, depending on the financial and legal situation.

At high speed monitoring the skid resistance is measured indirectly, so quality management and calibration procedures for all involved parts are necessary, namely tyre, force transducer, wheel load etc.

Skid resistance is a speed dependent value, so exact speed recording while measuring is important. As the measurement speed may have to be adapted due to traffic, a proven correlation for converting results to a default speed is necessary.

Together with skid resistance, macro texture measurements should be carried out. Macro texture has an influence on skid resistance at high driving speed and therefore minimum levels of macro texture should be defined. A measurement vehicle that allows the measurement of both properties at the same time is the optimal solution. Macro texture is usually measured with laser sensors, so the measuring unit must be mounted in front of the wetting unit, as laser measurements are possible only on dry surface.

Figure 2 Skid resistance - ROAD STAR, AIT, Austria (SPENS 2008)

Figure 3 Skid resistance - GripTester, TU Vienna, Austria (SPENS 2008)

2.2.2.4 Surface defects assessment

The basic surface defects assessment is visual inspection, although advanced video recording techniques are also used.

Table 5 Surface defect assessing devices in some EU countries

Country	Measuring Device
Austria	Video
Bulgaria	Visual inspection, Video Recording
Czech Republic	Visual inspection, Video Recording (ARAN, ARGUS)
Hungary	Visual inspection
Poland	Visual inspection, Video Recording (ARGUS)
Slovakia	Visual inspection, Video Recording (VIDEOCAR)
Slovenia	Visual inspection
Sweden	Visual inspection (Inspection manual, Bära eller Brista)

The visual inspections have to be performed by trained and qualified personnel. A work procedure as well as a uniform catalogue of defects have to be provided.

2.2.2.5 Bearing capacity measurements

For bearing capacity Falling Weight Deflectometers are generally used. They are produced by a few manufacturers. The Deflectograph LaCroix is also used in some countries-

Table 6 Bearing capacity measuring devices in the countries considered

Country	Measuring Device
Austria	Deflectometer FWD
Bulgaria	Deflectometer FWD, Deflectograph LaCroix
Czech Republic	Deflectometer FWD
Hungary	Deflectometer FWD-KUAB, Deflectograph LaCroix (occasionally)
Poland	Deflectometer FWD
Slovakia	Deflectometer FWD - KUAB
Slovenia	Deflectometer FWD, Deflectograph LaCroix
Sweden	Deflectometer FWD

These devices are well-established for some time, so to ensure consistent results is not too difficult. Within the COST action 336 ‘Use of Falling Weight Deflectometers in Pavement Evaluation’ a calibration procedure was defined (1999), which is now well established. The calibration procedure involves the FWD device itself and its parts, and it is suitable for harmonisation of different devices.

Interestingly, there seem to be no attempts to establish a formal European standard or even International Standard for FWD measurements, even though there are more than 300 FWDs in use worldwide (as at 2001).

The harmonisation exercise conducted within in SPENS in 2008 showed, that the results of the measurements itself are well comparable. The calculation of E-modulus was not part of the harmonisation and is not part of COST 336. Here, different results are possible. Due to upgrading, reinforcement and rehabilitation of existing roads, there is often a lack of information about the layer thicknesses. As this is decisive for the bearing capacity calculations, FWD measurements can be supported by Ground Penetrating Radar measurements.

One drawback of the FWD method is that it gives just point information.

Due to its static measurement, some kind of safeguarding is required. On highly trafficked roads, measurements have to be done in the off-peak hours, possibly at night, which increases costs. For network analysis, Traffic Speed Deflectometers have been introduced in Denmark, Great Britain and the Netherlands. Continuous deflection profiles are derived from the measurement. The devices operate at speeds up to 80 km/h. These devices offer possible improvements over the use of FWD and may be considered for network wide measurements in the future.

Figure 4 Bearing capacity – different measurement devices (SPENS 2008)

2.2.3 SPENS – upgrading of low volume roads

Pavement management systems incorporate some form of priority programming procedure. The types of priority assessment methods vary from simple subjective ranking to sophisticated mathematical programming. Each has specific features in terms of the pavement rating parameters, type of economic analysis applied etc. Their four major steps: information, identification of needs, priority analysis, and output reports. Priority programming method can be grouped into one of the classes presented in Table 7.

Table 7 Classes of priority programming methods

Class of method	Advantages and disadvantages
Simple subjective ranking of projects based on judgment	Quick, simple: subject to bias and inconsistency: may be far from optimal
Ranking based on parameters, such as serviceability, deflection, etc.	Simple and easy to use; may be far from optimal
Ranking based on parameters with economic analysis	Reasonably simple; should be closer to optimal
Optimization by mathematical programming model for year-by-year basis	Less simple: may be close to optimal effects of timing not considered
Near optimization using heuristics and marginal cost-effectiveness	Reasonably simple; can be used in a microcomputer environment; close to optimal results
Comprehensive optimization by mathematical programming model taking into account the effects	Most complex; can give optimal program (max. of benefits)

In the deliverable D13 of the SPENS project ‘Systematic decision making methodology on the pavement rehabilitation and upgrading of low volume roads’ was described.

The suggested approach was suitable for flexible pavements on a network-level planning of low-volume roads. The suggested maintenance measures should be followed by more detailed analyses of the road condition on an object (project) level dealing with a homogenized section of road. At the object level more information must be provided – a detailed visual inspections as well as tests of the materials in pavement structures are usually necessary. The cause of the resulting damage has to be determined and, subsequently, pavement design and the selection of the suitable materials for rehabilitation must be done. For low volume roads it was suggested to use on of the following rehabilitation methods:

- resurfacing (surface dressing, slurry seal, thin overlay),
- overlaying (including local rehabilitation),
- strengthening (including local rehabilitation),
- "sandwich" method,
- recycling, and
- reconstruction.

2.3 Feedback from questionnaire: Current practice in different countries

The information on the existing management systems, degradation models and benefits of different management strategies regarding end-user service levels were investigated using questionnaires. Feedback to the questionnaire was received from Austria, Croatia, Slovenia and Sweden. The expert described what performance indicators are employed to measure the standard of the infrastructure, what interventions are commonly applied and what management strategies are used.

2.3.1 Austria

The pavement management system (PMS) detailed in the "Handbook of Austrian Pavement Management System" [PMS Consult 2009] summarises the practical experience gained through the application of a PMS in Austria over the past 12 years. In particular, the focus lies on the practical aspects rather than including all the mathematical models and derivations that form the background to the equations described in chapter 3.3.2 (Current practice in Austria – Indicators and degradation models used for maintenance measures.

The core of the Austrian PMS is the prediction of the overall road condition based on the prediction of individual characteristics of the pavement. Following this prediction, it can be investigated which interventions or measures (in time and space) create the smallest costs or negative effects. However, the results of such a prognosis are not directly translatable into a construction programme, but rather require post-processing by the responsible engineers to find a method that is implementable.

The Austrian PMS is based on a system known as VIAPMSTM (stemming from an originally Canadian system) and has been used across the entire ASFINAG network (motorways and carriage ways) since the year 2000. The need for a transparent PMS arose in the light of the ever increasing traffic loads, especially in terms of HGVs, that were witnessed over the last decade. In addition to this, the rising age of pavements in connection with a relative reduction in new pavement construction called for the need of an objective decision making process.

The general targets of the Austrian PMS are seen to be the following:

- objective presentation of the current pavement condition on the basis of acquired data and information (condition data, pavement data, traffic data etc.)
- determining the maintenance targets in terms of the requirements on traffic safety, driving comfort, structure, environment etc.
- economic assessment of maintenance strategies with respect to the maintenance targets.
- estimating the development of maintenance needs in connection with the development of pavement condition and with respect to maintenance targets.
- optimized ranking of maintenance measures.

A more specific target of the PMS is to come up with estimates of maintenance needs for the entire road network (network-level), while also being able to work on suggestions for maintenance measures of individual stretches of road (object-level). The latter should form the basis for more detailed investigations that lead to interventions/measures in the frame of individual maintenance projects.

Generally, it can be said that the maintenance targets used in the Austrian PMS are chosen such that the highest possible pavement quality is achieved under the given boundary conditions (budgetary restrictions) from both, the point of view of the road user and the view of the road operator. These targets can be summarised as follows:

- maintaining a level of safety
- maintaining driving comfort
- maintaining the structure/substance as such
- minimizing negative environmental impacts
- minimizing traffic hindrances to users

With regard to these maintenance targets, evaluating the effect of the PMS requires the definition of two sub-indices:

1) a serviceability index (GI) which describes safety and driving comfort, and

2) a structural index (SI) which describes the structural state of the pavement construction.

The former can be regarded to represent the condition from the point of view of the road user, while the latter tends to be of greater interest to the road operator. To provide a comprehensive description of the pavement condition, these two sub-indices can be combined to give an overall index (total condition index GW) which allows a simplified definition of the target function. How each these values is calculated is explained in more detail under the section 3.3.2.

Currently there are no sub-indices to describe the environmental effects or the use costs, but these would be useful in future to assess the positive and negative effects of interventions.

2.3.2 Belgium

The Belgian road network is divided in three regions : there are efforts to develop management systems in each of the three regions. We have focused our study on the Flemish region, one of the reasons being that it is one of the funding authorities for the Eranet road program.

We conducted an interview and we gathered the following facts. The future PMS will include four parameters. One index ranging from 0 to 100 will be calculated for each parameter, one global index will then be established. The global index will be calculated as the minimum value amongst the following four parameters: Road Evenness, Ruts, Skid resistance and a Visual parameter (based on inspections). Each index will be averaged per section of 100m and normally one measure will be taken every 5m.

One formula per parameter and per type of pavement will be available.

The evolution will be a function of the number of axles (ESALS) and won’t be a function of time.

The following parameters are used :

- Evenness : with a Laser from the ARAN (around 10 to 20% overestimation vs. APL : 10% for the big wavelengths and 20% for the smaller). The network will be assessed once a year
- Visual index : automated with the ARAN (cracks) and visual inspections will be carried out
- Skid resistance: with a SCRIM at 70km/h
- Ruts : the ARAN will be used.

The triggers for the maintenance are 50 for evenness (30 for secondary network) and Visual Index. A limit of 40 is chosen for the Skid resistance and the rutting, these smaller limits are directly related to the safety of the end-user.

There will be 9 types of maintenance described in the PMS.

The costs are described in function of the maintenance type and not in function of the deterioration level.

The unit is the square meter for the pavement or the cm (height) per m² for the deeper layers. If the cost is based on the surface, the cost will take into account the type of lane for multiple lanes roads (e.g. : emergency, first lane for HGV and other lanes)

Social Costs : these are not taken into account at this time.

2.3.3 Croatia

Visual condition assessment: In Croatia, condition assessment of pavement surfaces includes visual inspection, by car, and collection of the following data: type, area (or length) and severity of cracking (alligator, block, longitudinal and transversal) and of surface defects (bleeding, patching, ravelling and spalling). Standard investigation area is 100 m length of a traffic lane. Also, video logging is used for additional pavement distress data inspection. Detailed visual inspection on motorways is planned to be carried out every four years. No technical specifications exist for these types of inspections (internal guidelines only).

Transverse evenness – Rutting: Transverse evenness is expressed with the rut depth [mm]. Measurements are conducted automatically, at intervals of 10 m. Measurements are planned for every four years.

Longitudinal evenness: Longitudinal evenness is expressed through the International Roughness Index IRI [m/km]. The measurements are carried out on motorways every 4 years with equipment named 'Laser Prof' (Greenwood Engineering) at normal traffic speed, with a maximum exceeding 150 km/h. Measurements are planned for every four years.

Skid resistance and texture: Skid resistance is measured using SCRIM equipment, expressed in Sideways Friction Coefficient, SFC (60 km/h). A laser (LaserProf by Greenwood Engineering) is used for screening the texture, and the result is Mean Profile Depth, MPD [mm]. Skid resistance and texture are planned to be measured every two years.

Bearing capacity: For the purpose of assessment of pavement structural behavior, FWD measurements are made every four years. The results are interpreted by Surface Curvature Index (SCI_{300}) or Residual Life (RD).

Noise – not measured

Emissions – not measured

2.3.4 Slovenia

Visual condition assessment: Visual condition assessment on motorways includes collection of severity and area of the following distresses: alligator cracking, linear cracking, patching, deformation; cracking, ravelling, potholes, patches. It is expressed with the Modified Swiss Index (MSI), which can reach values from 0 to 9. The inspections are carried out on motorways every 5 years. A video system was recently introduced, but assessment is currently done manually. No technical specifications exist for these types of inspections (internal guidelines only). In the future visual pavement condition assessment should be automatic (video or laser acquisition and automatic distress detection).

Rutting: Transverse evenness is expressed with the rut depth [mm]. Since rutting is not a very frequent defect on motorways, rut depth is measured manually on parts of the network where ruts are visually detected; every 20m, where a 4m straight edge is laid in transverse direction.

Longitudinal evenness: Longitudinal evenness is expressed through the International Roughness Index IRI [m/km]. The measurements are carried out on motorways every 4 years with equipment named 'Profilograph ZAG' at the speed between 80km/h and 120km/h. No video system is currently used. Technical specification (issued in 2003) TSC 06.610: 2003 Lastnosti voznih površin, Ravnost (Pavement surface properties, Evenness)covers measurements and assessment issues.

Skid resistance and texture: This is expressed with the Skid resistance coefficient SR (-). The measurements are carried out on motorways with equipment named 'Scrimtex' at the speed of 80km/h. The measurements were carried out once (in 2008). Skid resistance is planned to be measured every 5 years. A laser is used for screening the surface texture. National technical specifications for skid resistance were issued in 2002 titled TSC 06.620: 2002 Lastnosti voznih površin, Torna sposobnost (Pavement surface properties, Skid resistance).

Noise – there are initial measurements performed when a motorway section is opened, but no regular monitoring takes place afterwards.

Emissions – not measured

2.3.5 Sweden

Technical parameters are collected mainly by an integrated system with lasers, profilometer and camera. Data collection is procured using a pre-qualification procedure for certifying that bidders are able to achieve adequate capacity and quality, followed by a bidding procedure. Methods regarding equipment performance and data processing are specified. This means that data is delivered by different contractors but with equal data format and precision. For basic technical parameters such as rutting and IRI, data collection has been running continuously, full scale, since late 1980s. However new technical parameters has been added such as MPD (mean Profile Depth) indicating macro texture, edge deformation and improvements such as GPS data.

The **road surface geometry** is measured by a profilometer measuring with 15 and 17 laser cameras (depending on road width and if thick road markings is present) gyro and positioning with GPS.. The requirement is that at least 17 points on a width of 3,20 meters must be used in the calculations of rut depths.The lateral position of the measurement vehicle is of importance and subject to regulations. Two lasers positioned in each wheel path, 0.75 m to the left and right of the vehicle center, collects detailed longitudinal profiles for profiles, texture and evenness parameters.

The **overall condition** is documented by pictures which can be visually inspected. The pictures are taken in forward direction.

The parameters (performance indicators) finally reported to PMS database are as follows

Table 8 Sweden - Performance indicators reported to PMS database

Parameter	Unit	Presentation length
Longitudinal profiles (3)	mm	100 mm

IRI, Left and Right (2)	mm/m	20 m
Mean cross profile (1)	mm	1 m
Rut depth: Max, Left, Right (3)	mm	20 m
Cross fall	%	1 m
Curvature	1/m	20 m
Slope	%	20 m
Macro texture (Mean Profile Depth) in three lines along measured road (3)	mm	1 m
Standard deviation MPD (3)	mm	1 m
Mega texture Left and Right (2)	mm	1 m
Edge height	mm	1 m
Pictures (1280x960)	-	20 m
Position (SWEREF 99 TM)	m	20 m

New parameters are developed to better describe road user needs and to provide road managers with better decision making information. A crack parameter is specified and data collection and processing procedures are under implementation. Other examples of new parameters to be implemented are:

- Rut area, cross sectional area below fictive thread
- Local unevenness, a quarter car model using signed speed is applied to the measured longitudinal profile. The absolute value of the models chassis acceleration presented per meter is used as indicator
- Theoretical water area, theoretical water area based on cross section
- Rut bottom distance, distance between maximum left and right rut depth values
- Rut width, distance between support points for fictive thread

Skid resistance is not routinely measured as this is normally not considered to be a problem on Swedish roads during the “bare pavement season”. During summer problems with bleeding pavement can occur in hot weather conditions on roads with a high content of binder in the surfacing. On some high-traffic roads in Stockholm there have also been problems with low skid resistance during autumn due to polishing of high quality stone material. Skid resistance measurements are only carried out when there is a risk for low friction. The device used is a Saab Friction Tester. It operates on the principle that the measuring wheel (placed between the rear wheels of a Saab car) is to give a fixed slip ratio of 17% between it and the speed of travel along the wetted pavement surface. The wheel slips as it is towed along the wetted pavement surface at a constant speed and the slipping force is measured. The tire is of the type Trelleborg T49 with the dimensions 4.00-8/4.

According to the Swedish Air Quality Regulation (SFS 2010:477) each municipality must control that the European directive on air quality (2008/50/EC), concerning limit values for among other things carbon dioxide (NO_2) and particles (PM_{10}), is fulfilled. Measurements of particles and other emissions are routinely carried out many Swedish cities, especially the larger ones, where air quality limit values are exceeded in street environments.

The use of studded tires in Sweden (also Norway and Finland) causes high emissions of road wear PM_{10} during winter and early spring, why pavements are especially important for air quality in these countries. The studded tires are the main cause to exceedances of the directive limit values for PM_{10} why a lot of measurements and abatement research is focusing on how to decrease road wear contribution to PM_{10}. Research is carried out including dust binding and street sweeping as well as investigations on how to optimize pavements for reduced wear PM10 production.

Pavements have been replaced to reduce PM_{10} concentrations in the city of Norrköping. Stockholm, Göteborg, Norrköping and Uppsala are working with chemical dust binding and street sweeping as well as studded tire bans on certain streets to reduce road dust emissions.

2.3.6 Conclusions

All countries use measurements of skid resistance, longitudinal and transverse evenness and visual inspections to monitor the road condition. Most of the countries monitor also other parameters like bearing capacity, very few monitor environmental parameters like noise, PM_{10}. Measurement and evaluation of results are carried out according to national standards. Measuring devices throughout European Union countries are not harmonized. Since the measuring equipment is not standardized, the measured values are mostly not comparable even for the same technical parameters and/or indices; only some of the measurements are specified in norms EN 13036-1 to EN 13036-8.

Countries use a kind of pavement condition classification, yet the classifications differ a lot.

Similarly, the Key Performance Indicators that are used by NRAs, may be completetly different between neighboring countries.

Also intervention thresholds are different in various countries and depend on many factors (traffic loads, road class).

The methodology of a uniform pavement management system should be independent of all of those factors.

In order to follow a pavement management process, it is necessary to transform the pavement condition information into condition classes for each pavement parameter according to the actual national best practice and technical specifications. However the actual rehabilitation technique has to be selected on the project level to fulfill end user expectations.

The main conclusion that could be drawn from the answers was that current pavement management systems (PMS) function according to national specifications since there are no European standards. Moreover the PMS are different and they are implemented on a research level.

2.4 Individual and combined performance indicators

2.4.1 Introduction

Single performance indicators can be combined into indices relevant to road users and society, such as:

1) Road safety (functional performance)
2) Riding comfort and satisfaction (functional performance)
3) Pavement structure (structural performance of pavement)
4) Environmental and health factors
5) Society, road user and road manager costs

2.4.2 Literature review

Performance indicators are usually defined for different types of pavement structures (asphalt, concrete) and road categories (motorways, primary roads, secondary roads, urban roads). Within the ASCAM project, we focused on motorways. Several single performance indicators can be derived from technical parameters. The next step is the grouping of these single performance indicators or indices into representative combined performance indices as

• Functional performance indices (demands on road pavements by road users)

• Structural performance indices (structural demands to be met by the road pavement)

• Environmental performance indices (demands on road pavements from an environmental perspective).

The importance of these parameters depends on the type of road (traffic) and country (environmental awareness).

PIARC: PIARC [2] recommends that a General Performance Indicator (GPI) can be calculated as a weighted average of different Single Performance Indices or already Combined Performance Indices from different categories (i.e. structural and functional).

$$GPI = \frac{\sum_i PI_i \bullet W_i}{\sum_i W_i}$$

Where:

PI_i – is Performance Index (PI) number i

W_i - is the weight assigned to PI number i.

Austria and Germany use similar approaches in developing a GPI. First, combined indices for safety, comfort and structural adequacy, which are based on single performance indices, are calculated and then these two are combined into the GPI.

Austria: Austria uses a Total Condition Index (TCI) that is obtained from two combined indices: The structural index (SI) (a function of condition and age) and the comfort and safety index (CSI)

The expression is: TCI = max (CSI, 0.89*SI)

The Total Condition Index is used at network level, on motorways and primary roads only. The scale is 1 (very good) to 5 (very poor).

Germany: Germany uses a Total Condition Index (GW) that is obtained from two sub-indices: The substance subindex (TWSUB) (structural index) and the comfort and safety subindex (TWGEB).

The expression is: GW = MAX(TWGEB;TWSUB)

The GW index is used for network level analysis on all road categories. The scale goes from 1 (very good) to 5 (very poor) and there are 8 condition classes.

2.4.3 Implementation of Combined performance Indicators - COST Action 354

The main objective of the COST Action 354 was the definition of uniform European performance indicators for road pavements, taking the needs of road users and road operators into account. Within COST 354 it was desired that a General Performance Indicator comprises all aspects of pavement performance, including safety, comfort, structural adequacy and environment. But during the course of the action it was found that there was still limited information concerning environmental indicators.

Whereas the procedure proposed by the COST 354 action could theoretically be used for all four Combined Performance Indicators (CPI) for safety, comfort, structural performance and environmental impact, in practice the General Performance Index (GPI) is only a combination of the three first ones.

The combination procedure takes into account the maximum weighted CPI value affected by biased values of other weighted CPIs. So it is possible to ensure that the final result of the GPI is strongly influenced by the maximum weighted CPI. The weights (W_i) assigned to each Combined Performance Index must be selected by the user. In this case the weights may differ for each type of road network and for each country.

For the practical application of the combination procedure two alternatives were developed:

Alternative 1: This procedure considers the mean value of the Combined Performance Indices (CPI_i) affected by a weighting factor (W_i) other than the maximum weighted CPI influenced by a factor *p* and;

$$GPI = \min\left[5; I_i + \frac{p}{100} \cdot \overline{(I_2, \ldots .. I_n)}\right]$$

Where $I_1 \geq I_2 \geq \ldots \geq I_n$

$I_1 = W_1 \,.\, CPI_1$ $\quad$ $I_2 = W_2 \,.\, CPI_2$ $\quad$ $I_n = W_n \,.\, CPI_n$

Alternative 2: This considers the second largest weighted CPI influenced by a factor *p*.

$$GPI = \min\left[5; I_i + \frac{p}{100} \cdot I_2\right]$$

Where $I_1 \geq I_2 \geq \ldots \geq I_n$

$I_1 = W_1 \,.\, CPI_1$ $\quad$ $I_2 = W_2 \,.\, CPI_2$ $\quad$ $I_n = W_n \,.\, CPI_n$

In order to be able to make recommendations concerning the weighting factors to be assigned to each CPI, a short questionnaire was distributed within COST 354 and the replies from road administrators and road operators were merged. From the results it could be seen that safety was generally the indicator with the highest relative importance, and environment was the one with the lowest. At that time, only the influence of road pavement (and not road traffic) was taken into account, and its specific influence on environment is limited. The ratings assigned to the environmental indicator will most probably be higher when more data is available, moreover, the environmental awareness in Europe is increasing. Using the results from the questionnaire as a background, a set of weighting factors was suggested for the alternatives 1 and 2. These weighting factors are presented in Table 10.

Table 9 Proposed weighting factors (COST 345- final report)

	Road Safety	Riding Comfort	Pavement Structure	Environmental	Social Costs
Motorway	1,00	0,70	0,65	0,25	No data
Primary roads	1,00	0,70	0,80	0,30	No data
Secondary and other roads	1,00	0,65	1,00	0,35	No data

The COST Action 354 did not intend to impose indices or weighing factors but did provide a general scheme that can be adapted and tuned to the needs of the road administrator, taking into account whatever data are available.

Since the publication of the final report of the COST 354 action, the results were disseminated in Europe and in the US. The report became an important reference document for pavement management and a source of inspiration. The method for the determination of combined indicators is currently developed further beyond pavement management. The main difficulties that are encountered seem to be:

- the determination of aspects other than the technical properties of the assets that should be taken into account by asset management,
- the non-existence of “low level”, “measurable” indices that allow evaluating these aspects beside the technical properties of the assets, and
- the parameterisation of the asset management model (setting of priorities, weighting factors,…).

Most ERANET Road projects of the call on Asset Management are inspired by the results of the COST 354 action and contribute in some way or another toward an answer to the difficulties mentioned above.

The method proposed by the final report of the COST 354 action was also used by Working Group 2 of the PIARC Technical Committee D1 (cycle 2007-2011), as reported at the World Road Congress (September 2011). This working group addressed the issue of “high level management indicators” (HMLI) for asset management. Next to purely technical aspects of management of pavements and other road assets, road asset management must take into account all kinds of expectations of a large number of stakeholders. The working group developed a method for managers allowing them to develop their own HMLI. The proposed methodology consists of the following steps:

1. Identify all the stakeholders in road asset management, distinguishing, if necessary, different socio-economic sub-categories.
2. For each stakeholder category, determine the stakeholder’s concern(s) in road management and their expectations in road asset management and characterise the priority of these various expectations.
3. For each expectation, find a definition for one or several indicator(s) which would provide a measure of that expectation and examine whether it already exists.

4. If a measure does not exist, try to identify the elementary parameters on which it should be based, review whether these parameters already exist or whether it is necessary to build them (principle, measurement method…) and propose some method to aggregate and combine them to get a HLMI.

The whole approach as well as the combination of indices into HLMI is inspired by the method proposed by the COST 354 action.

2.5 Conclusions

The basis for every Pavement Management System (PMS) is an extensive database. Depending on the quality and amount of data gathered and the suitability of the models used to analyse these data, the economically most effective actions can be taken. The data bases need to be open and flexible, so that new or more refined parameters can be included into them. Since environmental awareness increases, it will become necessary to include parameters on noise, pollutants (PM_{10} and NO_2 concentrations or the discharge of polluted splashing water) or perhaps the negative influence of the road layout on the landscape. A data base has to enable data exchange with other databases, archiving and user-friendly updating of the data.

Predicting pavement condition in the future requires the acquisition of the current condition of road assets and models to predict degradation in time. Many tools exist to acquire the parameters describing the condition of pavements, but few degradation models have been employed in practice in pavement management. For application of PMS we need

- Inventory data - general road network data,
- Road condition monitoring data,
- A maintenance database.

The network referencing system can be arranged in different ways – many parameters such as the class of road, the road number, road section, chainage etc. must be taken into account when building a referencing system. There are a lot of important inventory data such as the width of lanes, traffic loads, structures, footways, layout, curvatures, crossings etc. Every country has built a road data base in its own, specific way. It is obvious that databases for pavement managements system are not easily compatible.

The design of pavements and materials used for road construction differ throughout countries, as well as the climate conditions. This is why degradation models for pavements must differ. Hence the pavement parameters measured to establish their condition do not differ much. Road condition monitoring is largely used in all countries for maintenance planning. It usually consists of road surface monitoring and road bearing capacity monitoring.

Road condition is evaluated in the form of the damage extent with respect to certain pavement characteristics. The pavement characteristics quantitatively and qualitatively describe pavement condition and can be physical values, indices or relative values. The characteristics apply to a certain length of road section and in many countries the characteristics are calculated by averaging over a 50 m long road section. The condition of the road surface is monitored on a network level by rutting, longitudinal evenness, skid resistance, surface properties and cracks. Most of the measurements are not yet standardized, yet some of them are described in the EN 13036-1 to EN 13036-8 standards.

Skid resistance is a very important parameter strongly related to end users service level “safety". It is measured by a friction index on the pavement. The high speed test, suitable for a network level approach, involves a tyre with a special profile that is dragged over a wet pavement with constant slip. Through a constant pressure onto the pavement, the skid resistance can be calculated through the force required to pull the tyre, giving a dimensionless friction index. This method is not yet standardised, but the static pendulum test to measure slip/skid resistance of a small part of surface has been standardized.

Rutting is a significant characteristic with respect to safety (aquaplaning) and driving comfort. The value which characterizes the road surface condition is the maximum rutting depth (max. of the left or right tyre track).

Longitudinal evenness is defined in accordance with the International Roughness Index (IRI). It is obtained from measured longitudinal road profiles. It is calculated using a mathematical model, whose response is accumulated to yield the wavelength of the pavement evenness that is a roughness index with units of slope (m/km).

Surface properties are inspected visually by means of high speed visual monitoring on a network level. Video records of the pavement are part of the database. On the project level thorough visual inspection of defects such as cracking, rutting, spalling, bleeding, etc. are carried out by qualified personnel on site. Several methodologies exist to evaluate the surface damage index, which depends on the percentage of cracks, type, severity, their location etc. For this property, the assessment also varies depending on the type of pavement (asphalt or concrete). The inspections record the state of the pavement and usually give no assumptions as to the causes of cracking. Together with information on dewatering, cross-fall, etc. they may indicate the cause of the degradation of pavement.

The condition of a road structure is usually monitored by falling weight deflectometer (FWD) measurements. Since bearing capacity is an important parameter for planning the type of maintenance works, more data should be gathered on the project level to optimise the maintenance measures. Geo-radar measurement together with coring of upper asphalt (or concrete) and unbound layers, give basic data on the structure of the pavement. Testing of the pavement materials (asphalt characteristics, gradation curves of unbound materials) and establishing the freezing-thawing resistance are also important parameters especially for roads with low bearing capacity. It is recommended to categorize the condition of the entire road structure and include it in the PMS.

Maintenance databases should be updated regularly to inform the pavement manager of all maintenance measures taken – unplanned minor interventions as well as renewal of the entire pavement structure.

Another aspect of roads, that should be considered in the PMS is the layout of a road section, i.e. is its cross section (number of lanes), cross-traffic, dewatering etc.

For pavement management it is usually suggested to derive several single performance indicators from the monitored technical parameters. The pavement performance indicators depend on the type of pavement structures (asphalt, concrete) and the road categories (motorways, primary roads, secondary roads, urban roads). Several methods are suggested and used.

Within the COST Action 354, uniform European Combined Performance Indicators (CPI) for road pavements, taking into account the needs of road users and road operators, were defined in 2008. Four CPI's, i.e. for safety, comfort, structural performance and environmental impact, were defined. However little data exist about environmental impact, so it is suggested that the General Performance Indicator is only a combination of the three first indicated. COST 354 provides a general scheme that can be adapted and tuned to the needs of the road administrator, taking into account whatever data are available. Working group of the PIARC Technical Committee D1 adopted this methodology and also developed a method for pavement managers to introduce 'high level management indicators' for asset management. These indicators should also involve all kind of expectations of large number of stakeholders.

In ASCAM an attempt has been made to establish the relation between the improvement of pavement characteristics, end user service levels and costs. The costs of construction works depend a lot on the location, length of section under repair, as well as the cost of congestion, change of driver safety during maintenance works etc. So it is difficult to derive a typical value of these costs. It is also difficult to relate one pavement characteristics to the end use service level. Even for skid resistance, which is obviously related to safety, many other factors must be taken into account when driver safety in general is discussed (crash type, traffic speed, traffic flow, horizontal curvature, social factors). Skid resistance is related to braking distance and only to skid-related crashes, particularly wet weather crashes. It is very difficult to quantify the relationship between crashes and skid resistance since it is site specific and influenced by a number of factors other than skid resistance. .

3 Task 2.2: Pavement condition assessment and prediction

3.1 Introduction and current practice

Many factors influence the pavement – with the help of monitoring and degradation curves, one is able to predict the future degradation or its condition development.

3.1.1 Austria

Predicting pavement condition requires the acquisition of the current condition. This is measured in the form of the damage extent with respect to certain characteristics. The characteristics used in the Austrian PMS serve the purpose of quantitatively and qualitatively describing pavement condition. The condition characteristics are defined through measurement values for a specific section of the road network and can therefore be physical values [m, m^2, m/km] or relative length or area values [%]. The length of a section for which a characteristic value is defined depends on the measurement data and the application of the information, but in general, the standard in Austria is to use 50m sections in which the values for different characteristics are defined.

3.1.1.1 Key performance indicators (KPI) for pavements

In the course of applying the Austrian PMS on federal and state roads, the following five independent characteristics have proven to be the most useful to classify road condition: rutting, longitudinal evenness, skid resistance, surface properties and cracks. The acquisition or measurement method of each of these properties is defined in national guidelines (e.g. RVS 11.06.67). Their use within the Austrian PMS will subsequently be described in more detail.

Rutting: This is a significant characteristic with respect to safety and driving comfort, and the value which is relevant to define the state of the pavement is the maximum rutting depth (max. of the left or right tyre track), where the values are calculated by averaging over a 50 m stretch of road.

Longitudinal evenness: This is defined in accordance with the international roughness index. Again, it is computed over 50 m and takes on the dimension m/km to describe the wavelength of the pavement evenness a simplified standard vehicle would encounter. The method for measuring and computing this characteristic value is given in the national guideline RVS 11.06.68.

Skid resistance: The friction index on the pavement is the defining characteristic for skid resistance, which is another property that is strongly related to safety. The method employed in measuring this characteristic is referred to as the Stuttgart method, which involves a tyre with a special profile that is dragged over a wet pavement at 60 km/h with a constant slip. Through a constant pressure onto the pavement, the skid resistance can be calculated through the force required to pull the tyre, giving a dimensionless friction index (see guideline RVS 11.06.65). Again, the acquired data is summarised in 50m-sections.

Cracks: Structural properties of pavements can be defined through the percentage of cracks on the surface. This is evaluated on through visual inspection (video records of the pavement), where – depending on crack type – the length or area of cracks along the pavement is determined. For this property, the assessment varies depending on the type of pavement (asphalt or concrete) and the measurements purely record the state of the pavement and allow no postulations as to the causes of cracking.

Surface damage: This is the only characteristic which summarises a variety of different forms of damage into one generic group. Again, a differentiation between surface damage on asphalt and concrete roads needs to be made.

3.1.1.2 Indicators and degradation models used for maintenance measures

Once the characteristics mentioned above have been measured/computed for 50m stretches, these sections are grouped together according to the so-called change-point method (probabilistic approach) to for homogeneous sections of pavement. This is simply done as a form of data reduction, as each homogeneous stretch of pavement will only have one value for each of the five above-mentioned characteristics assigned.

In the course of the practical application of the Austrian pavement management system, two forms of loading have proven to be sufficient in representing the loads which pavements are subject to. These are traffic loads and climatic loads. The influence of other factors such as chemical (exhaust gases, fuels etc.) and other mechanical inputs (e.g. winter service – chains, ploughs etc.) are not sufficiently known or measureable, or can even be assumed to be negligible in the first place.

In order to predict the development of pavement condition over the years with the help of the five key characteristics, the traffic loading needs to be defined in the form of traffic density i.e. an annual daily average of cars and lorries per 24hrs. Surveys and statistics of these numbers exist in most countries, usually even permitting a forecast of traffic development in the upcoming years. The values used for “climatic loading” of road pavements are the temperature minimum and maximum [^{o}C], a frost index [^{o}Cd] and an annual precipitation sum [mm].

Calculating indices to assess the pavement condition: The indices defined under point “2. Aims” were a serviceability index (*GI*), a structural index (*SI*) and an overall index (*GW*). In short, these are obtained through a normalisation of the measured characteristic values, followed by a weighted combination of the normalised values to produce the sub-indices. Subsequently, the overall index is a weighted combination of the sub-indices.

The normalisation of the five measured characteristics provides a way to transform them into a dimensionless value between 1 and 5, with 1 = very good and 5 = very bad.

Normalisation

Rutting: $ZW_{SR} = 1.0 + 0.175 \cdot ZG_{SR}$ [$1.0 <= ZW_{SR} <= 5.0$]

ZW_{SR} …… Normalised rutting value

ZG_{SR} …… max. rut depth measured [mm]

Skid resistance: $ZW_{GR} = 9.9286 - 14.286 \cdot ZG_{GR}$ [$3.5 <= ZW_{GR} <= 5.0$] or $ZW_{GR} = 6.5 - 6.6667 \cdot ZG_{GR}$ [$1.0 <= ZW_{GR} <= 3.5$]

ZW_{GR} …… Normalised skid resistance value

ZG_{GR} …… Skid resistance as measured (friction index) [1]

Longitudinal evenness: $ZW_{LE} = 1.0 + 0.7778 \cdot ZG_{LE}$ [$1.0 <= ZW_{LE} <= 5.0$]

ZW_{LE} …… Normalised longitudinal evenness value

ZG_{LE} …… Longitudinal evenness as measured (international roughness index) [mm]

Cracks: $ZW_{RI} = 1.0 + 0.35 \cdot ZG_{RI}$ [$1.0 <= ZW_{RI} <= 5.0$]

ZW_{RI} …… Normalised crack value

ZG_{RI} …… Cracks as measured [%]

Surface damage: $ZW_{OS} = 1.0 + 0.0875 \cdot ZG_{OS}$ [$1.0 <= ZW_{OS} <= 5.0$]

ZW_{OS} …… Normalised surface damage value

ZG_{OS} …… Surface damage as measured [%]

Calculating Sub-indices GI & SI

The serviceability index GI is a sub-index composed of two aspects: traffic safety and driving comfort. Each of these is in turn comprised of the normalised values for skid resistance, rutting, longitudinal evenness and surface damages.

The structural index SI is a function of the normalised values for cracks, surface damages, rutting and longitudinal evenness, as well as a factor for pavement age (which depends on the type of cover – concrete or asphalt). Together with in index for load bearing capacity, these factors produce the structural index.

Weighted combination

The overall index GW describing the overall pavement condition is simply a weighted combination of SI and GI. Similar to SI and GI, GW can take on a value between 1 – 5, which corresponds to 1… very good, 2… good, 3… intermediate, 4… bad and 5… very bad.

Pavement condition prediction

For each of the five pavement characteristics mentioned above, a deterministic prediction function has been found empirically.

Prediction of cracking with age: $ZG_{RI,g} = \exp[-3.60517 + a \cdot Alter_{Decke} + \ln(Alter_{Decke} + 0.01) - 0.5 \cdot \ln(VBI + 0.01)]$

$ZG_{RI,g}$ …… extent of cracking on surface [%]

a …… factor whose value is obtained from a table depending on the type of road structure dealt with

$Alter_{Decke}$ …… age of surface layer [years]

VBI …… traffic load coefficient (defined in “Handbuch Pavement Management 2009”)

Prediction of surface damage with age: $ZG_{OS,g} = -12.672 + a \cdot Alter_{Decke} + 0.00066 \cdot FIKh$

$ZG_{OS,g}$ …… extent of surface damage [%]

a …… factor whose value is obtained from a table depending on the type of road structure dealt with

$Alter_{Decke}$ …… age of surface layer [years]

FIKh …… frost index [khrs]

Prediction of rutting with age: $ZG_{SR,g} = a \cdot Alter_{Decke} + b \cdot NLW_{kum}/100000$

$ZG_{SR,g}$ …… extent of rutting [mm]

a, b …… factor whose value is obtained from a table depending on the type of road structure dealt with

$Alter_{Decke}$ …… age of surface layer [years]

NLW_{kum} …… cumulative load cycles over the investigated time period [millions] (defined in “Handbuch Pavement Management 2009”)

Prediction of longitudinal with age: $ZG_{LE,g} = a \cdot Alter_{Decke} + b \cdot NLW_{kum}/100000$

$ZG_{LE,g}$ …… extent of longitudinal evenness [m/km]

a, b …… factor whose value is obtained from a table depending on the type of road structure dealt with

$Alter_{Decke}$ …… age of surface layer [years]

NLW_{kum} …… cumulative load cycles over the investigated time period [millions] (defined in “Handbuch Pavement Management 2009”)

Prediction of skid resistance with age: $ZG_{GR,t} = ZG_{GR,t-1} - a$

$ZG_{GR,t}$ …… dimensionless friction factor μ in year t [e.g. 2011]

a …… factor whose value is obtained from a table depending on the type of road structure dealt with

3.1.2 Belgium

The Belgian road network is divided in three regions: there are efforts to develop management systems in each of the three regions. We have focused our study on the Flemish region, one of the reasons being that it is one of the funding authorities for the Eranet road program.

We conducted an interview and we gathered the following facts.

3.1.2.1 Key performance indicators (KPI) for pavements

The following parameters are used :

- Evenness : with a Laser from the ARAN (around 10 to 20% overestimation vs. APL : 10% for the big wavelengths and 20% for the smaller). The network will be assessed once a year
- Visual index : automated with the ARAN (cracks) and visual inspections will be carried out
- Skid resistance : with a SCRIM at 70km/h
- Ruts : the ARAN will be used.

The triggers for the maintenance are 50 for evenness (30 for secondary network) and Visual Index. A limit of 40 is chosen for the skid resistance and the rutting, these smaller limits are directly related to the safety of the end-user.

3.1.2.2 Indicators and degradation models used in existing practices

The future PMS will include four parameters. One index ranging from 0 to 100 will be calculated for each parameter, one global index will then be calculated and will be calculated as the minimum value amongst these four parameters. The parameters are: Road Evenness, Ruts, Skid Resistance and a Visual parameter (based on inspections). Each index will be averaged per section of 100m and normally one measure will be taken every 5m.

One formula per parameter and per type of pavement will be available.

The evolution will be a function of the number of axles (ESALS) and won't be a function of time.

The evolution laws are described in the annual publication of the Flemish Road Authority and are given hereafter :

Skid resistance (DWC) :

$DWC_n = 0.7 - 0.3 \times (1 - e^{-(n/N)})$

where N is the lifecycle in terms of ESALS and n is the ESALS at time t

Rutting (SPD) :

for highways, $SPD_n = 16 \times (n / 12)^{1/2}$ and

for national roads $SPD_n = 16 \times (n / 20)^{1/2}$

Visual inspections:

$Defect_n$ (in %) $= 100 / (1 + K^{-\log (n / N)})$

where K is a function of the pavement type (K=64 for asphalt and K=40 for cement concrete) and N is the design life (e.g. 20 years for asphalt and 40 years for cement concrete).

The end of life is defined as 50% of damage.

Road Evenness (VC) :

$VC_n = VC_0 + A \times (n / N)^B$ with $VC_0 = 60$, $A = 260$ and $B = 1$

3.1.3 Croatia

IGH Institute Inc, Zagreb, Croatia is designing and implementing a road infrastructure management system with the purpose of managing the structures administrated by the company Croatian Motorways Ltd. The system consists of seven subsystems representing structure groups: bridges, geotechnical structures, pavements, tunnels, drainage, road equipment and buildings. Each subsystem consists of three main parts:

- permanent data (list of the structures, position on the road network, traffic load data, data on the structure);
- variable data (data on structure condition, obtained by inspections) and

- management procedures (calculation of the current and forecasting the future condition indicators, determination of priorities and multi-year maintenance plans).

Pavement management system is based on the principles of the COST Action 354, where the technical parameters for pavement distresses are defined, and transformed to performance indices. To assess pavement condition, following distresses are recorded:

surface distress (cracks (cr) and surface defects (sd)),

longitudinal evenness (e),

transverse evenness (r),

skid resistance (f),

texture (t) and

bearing capacity (b).

3.1.3.1 Key performance indicators (KPI) for pavements

Technical parameters are values determined and measured during inspections and measurements performed on structures. Their results form the base for calculation of the structures performance indices, according to COST 354.

According to COST 354, performance indices for cracks ((PI cr), surface defects (PI sd), longitudinal evenness (PI e), transverse evenness (PI r), skid resistance (PI f), texture (PI t) and bearing capacity (PI b) are dimensionless numbers on a 0 (very good) to 5 (very poor) scale, which are transformed from the technical parameters (TP cr, TP sd, TP e, TP r, TP f, TP t, TP b) via the transfer functions proposed in COST 354. Single (Individual) performance indices (PI), adjusted by impact weighting factors (W pi), form the dimensionless combined performance indices (CPI) in relation to road safety (CPI s), user comfort (CPI c), pavement bearing capacity (CPI b) and environmental impact (CPI e). The combined performance indices (CPI) adjusted by the impact weighting factors (W cpi) are combined into dimensionless general performance index (GPI).

3.1.3.2 Indicators and degradation models used for maintenance measures

The size of investigation surface for determination of the technical parameters can be selected in the Pavement Management System computer application. Default values are a section length of 100 m with 10 m steps along the route, meaning that for every 10 m along the route, the technical parameters for the section 50 m before and 50 m after the current position are calculated.

Performance indices are transformed from the technical parameters via the transfer functions proposed in COST 354.

Technical parameters and performance indices define homogenous sections, to which type repairs will be assigned according to their condition.

With defining required conditions, different scenarios are created for the planned period. Performance indices are located on the *degradation/time* curve, and the procedure of *cost/condition* calculation, with new input parameters, is repeated for every year of the planned period. Between different scenarios, one is chosen that shows optimum relation of costs and structure condition.

In pavement condition analysis, two types of influence on pavement condition are considered: traffic and climate.

The traffic load is defined by average annual number of equivalent single axle loads (82 kN) and by assumed annual traffic increase. Effect of climate is estimated on the basis of temperature minimum and maximum [^oC], a frost index [^oCd] and an annual precipitation sum [mm].

3.1.4 Netherlands

From the literature review we can summarize that pavement condition is assessed in the Netherlands according to the national specifications named DWW wijzjer. Nummer 48a, 'Guidelines on the severity and extent of road surface damage' [4] available in English was examined. The following pavement parameters are taken into account: ravelling cacking, crazing (crocodile cracking), unevenness, loss of skid resistance and poor drainage. Bearing capacity, type of foundations and water table are not taken into account. Based on the measured values a combined so-called 'Damage index' is established. The Damage index has two subcategories

- Severity class (class 1, 2 and 3) and
- Extent category (A, B and C)

The qualitative evaluation of the road condition is shown in Table 10. The severity classes are defined for 100m long sections on one lane – the class boundary values are values averaged over a length of 100m. Since it is assumed that it takes one year from inspection to perform maintenance works, the actual rut depth taken into account is approximately 2mm lower that stated in the table.

- Severity class 1 means slight damage (No maintenance needed).
- Severity class 2 moderate damage (The need for maintenance depends on other types of damage),
- Severity class 3 serious damage (Immediate maintenance required)

Table 10 Qualitative evaluation of road condition in the Netherlands according to severity classes

Classes	Severity class	Severity class 2	Severity class 3
Pavement parameter			
Ravelling	Mortar loss, some aggregate missing	More aggregate missing form the surface	Aggregate layers missing
Cracking transverse cracks *width* *height difference*	<3mm <2mm	3 to 20 mm 2 to 10 mm	>20mm >10mm
Cracking longitudinal cracks *width* *height difference*	<3mm <2mm	3 to 20 mm 2 to 10 mm	>20mm >10mm
Crocodile cracking	Cracks not joined	Cracks joined	Cracks joined and some pieces loose
Unevenness – transverse unevenness – rut depth	>15mm	15-17mm	≥18mm
Unevenness – longitudinal unevenness - IRI	≤2,0	2,1 to 3,4	≥3,5

Loss of skid resistance – roughness values	≥0,45	0,44 to 0,38	≤0,37
Poor drainage – crossfall of the pavement surface	>1,5%	1,5 to 1,1%	≤1%
Maitenance	No maintenance necessary	1,5 to 1,1%	≤1%

For ravelling and cracking, the extent of damage is also determined for each severity class and assigned to the categories A, B and C. For longitudinal cracking and crocodile cracking, a further distinction is made between 'stable' (cracking only occurs in the upper layers) and 'unstable' conditions, when the lower layers are also affected.

Table 11 Qualitative evaluation of road condition in the Netherlands according to extent categories

Classes	**Extent category A negligible**	**Extent category B moderate**	**Extent category C extensive**
Pavement parameter			
Ravelling % of road surface	<15%	15% to 30%	>30%
Cracking transverse cracks - number	1 to 2	3 to 7	more than 7
Cracking longitudinal cracks - % of length *stable* *unstable*	<15% <15%	15% to 50% 15% to 30%	>50% >30%
Crocodile cracking - % of length *stable* *unstable*	<10% <10%	10% to 30% 10% to 20%	>30% >20%

For each severity class, the extent of transverse and longitudinal cracking, crocodile cracking and ravelling is determined over a representative lane segment of 100 m. The extent of ravelling for each severity class is established by determining the percentage of the surface over which ravelling of the same severity class occurs.

The extent of longitudinal and crocodile cracking is determined for each lane half, and then these values are added together and divided by 2. When determining the extent of damage on one half of the lane, the extent in severity class 3 is determined first, followed by the extent in severity class 2 on the remaining area of lane and finally of class 1. In this way the total cracking (e.g. longitudinal) in the three severity classes taken together cannot be more than 100% on a 100 m stretch of pavement.

3.1.5 Slovenia

3.1.5.1 Key performance indicators (KPI) for pavements

The key performance indicators that triggers maintenance actions on motorways are usually

Comfort: regulate maintenance measures are usually triggered by the ageing of asphalt (propagation of cracs, number of patches, low skid resistance)

Safety: upgrading (replacement) of safety barriers. Those measures usually include also construction of noise barriers (where necessary) that triggers widening of shoulders and renewal of pavement.

Degradation: on primary and other roads the key performance indicator for upgrading of road is the bearing capacity of roads which is usually insufficient due to increase of traffic loads. Extensive maintenance measures are triggered by safety – construction of overpasses, straightening of road layout, etc.

3.1.5.2 Indicators and degradation models used for maintenance measures

The degradation models shown below are being implemented on a research level only on motorways in Slovenia.

Visual pavement condition assessment

Surface damage: Visual condition assessment takes into account cracking, ravelling, patching and deformation. It is expressed with the Modified Swiss Index (MSI), which can reach values from 0 to 9. 0 means no deterioration and 9 means the most deteriorated pavement possible. The analytical function is shown in Figure 5.

$$MSI = 16 \cdot \left(1{,}0 - 1{,}0002^{-\left(AgeWC^{2,45}\right)}\right)$$

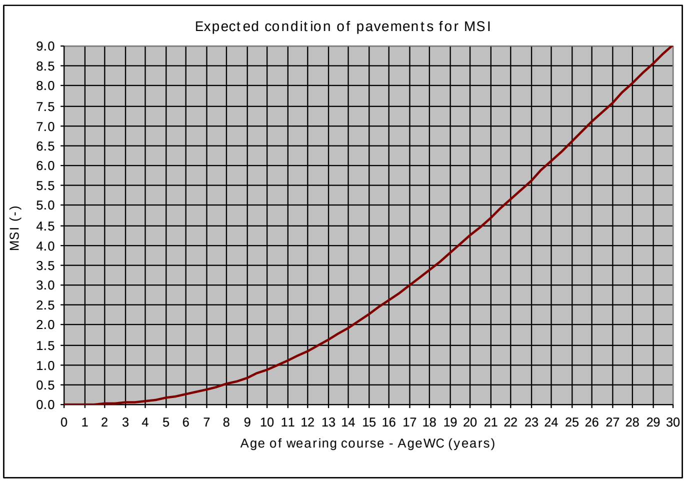

Figure 5: Expected condition of pavement, expressed with MSI

To normalize the function into the scale from 1 to 0, the analytical function changes to the following equation.

$$MSI = 1 - \frac{16 \cdot \left(1{,}0 - 1{,}0002^{-\left(AgeWC^{2,45}\right)}\right)}{9}$$

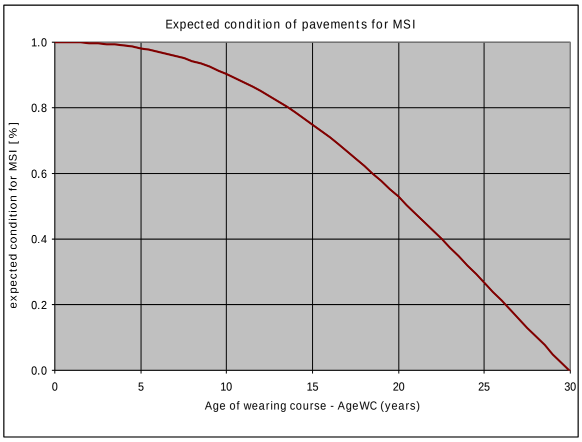

Figure 6 Normalized expected condition of pavement, expressed with MSI

The degradation process is monitored with a visual pavement condition assessment which takes place every 3 years. Visual pavement condition assessment takes into account cracking, raveling, patching and deformation. Every distress is assessed with the severity (from 0 to 3) and the affected area (from 0 to 3). Each distress type has a specific weight, all weights sum up to 1. Therefore the MSI (Modified Swiss Index) is calculated as

$$MSI = \sum_{distress} Weight \cdot Severity \cdot Affected\ \ Area$$

and can reach values from 0 to 9. MSI = 0 means no distress, MSI = 9 means the maximum possible distress.

Rutting - Transverse evenness:

Transverse evenness is expressed with the Rut depth [mm]. The analytical function is shown in Figure 7.

$$Rut = \frac{30}{35} \cdot AgeWC$$

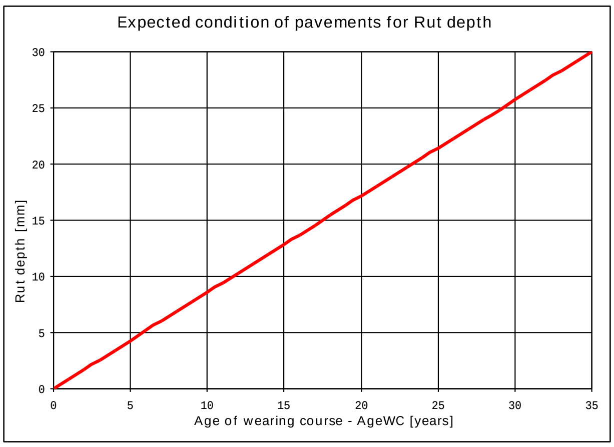

Figure 7 Expected condition of pavement, expressed with Rut depth (mm)

To normalize the function into the scale from 1 to 0, the analytical function changes to the following equation.

$$Rut = 1 - \frac{AgeWC}{35}$$

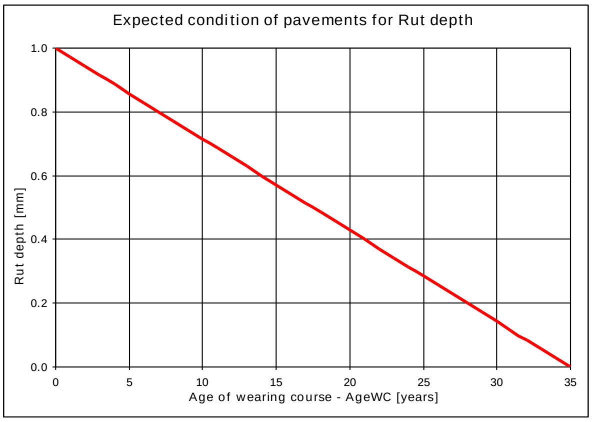

Figure 8 Normalized expected condition of pavement, expressed with Rut depth (mm)

The transverse evenness is laser based and is performed in the right wheel path on the motorways every 5 years. The calculation of the deviation from the true planar surface involves simulation of moving the 4m straightedge over the pavement's longitudinal profile.

Longitudinal evenness

Longitudinal evenness is expressed with the International Roughness Index IRI [m/km]. The analytical function is shown below.

$$IRI = 0{,}0031 \cdot AgeWC^{1{,}8} + 0{,}7$$

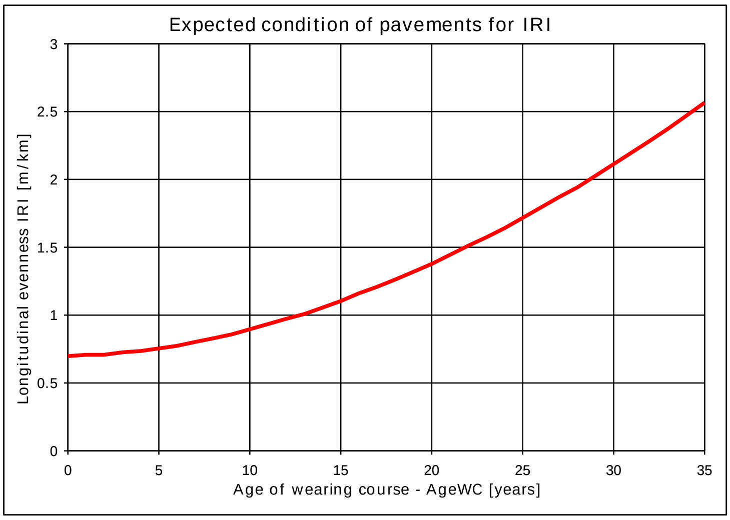

Figure 9 Expected condition of pavement, expressed with IRI

To normalize the function into the scale from 1 to 0, the analytical function changes to the following equation.

$$IRI = 1 - \frac{\left(0{,}0031 \cdot AgeWC^{1{,}8}\right)}{1{,}865}$$

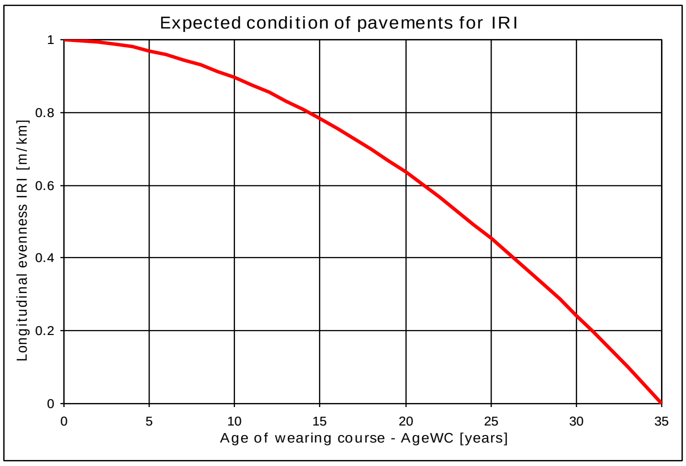

Figure 10 Normalized expected condition of pavement, expressed with IRI

Skid resistance

Skid resistance is expressed with the Skid resistance coefficient SR (-). The analytical function is shown in Figure 11.

$$SR = \max\left(0{,}2; -\frac{0{,}65}{35} \cdot AgeWC + 0{,}85\right)$$

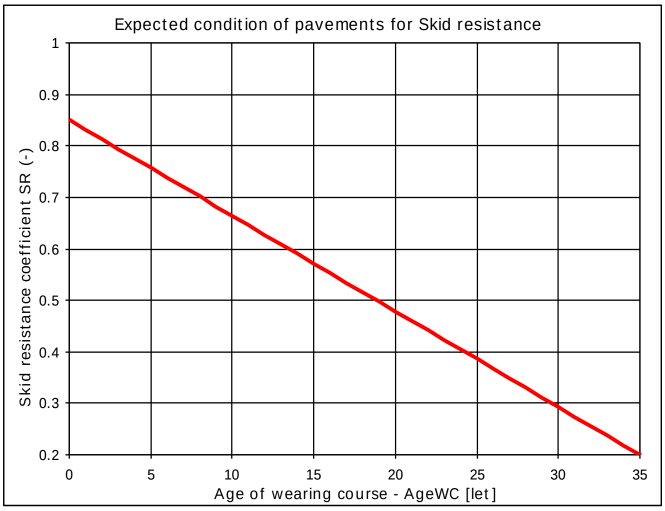

Figure 11 Expected condition of pavement, expressed with Skid resistance coefficient SR (-)

To normalize the function into the scale from 1 to 0, the analytical function changes to the following equation.

$$SR = 1 - \frac{AgeWC}{35}$$

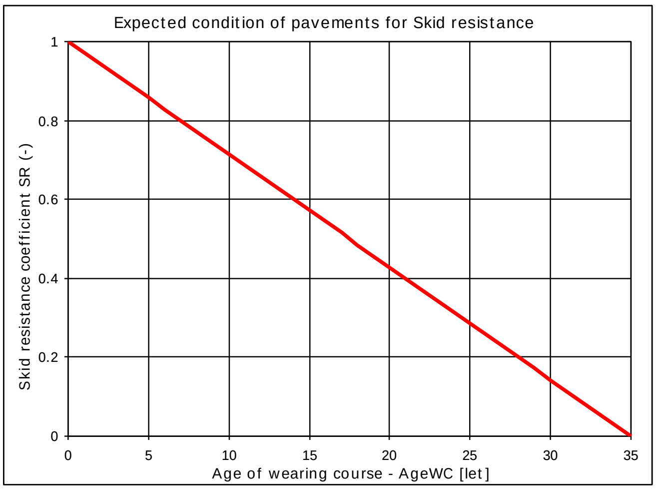

Figure 12 Normalized expected condition of pavement, expressed with Skid resistance coefficient SR (-)

3.1.6 Sweden

3.1.6.1 Key performance indicators (KPI) for pavements

Aggregated indicators are currently not used in Sweden. Instead, IRI and Rut depth (max) are used also for network monitoring and decision making.

The Swedish Transport Administration has recently published a document describing the so called “Maintenance standard for paved roads 2011” (Trafikverket Publikation 2012:074). The maintenance standard is a target standard for year 2021 which coincides with the end of the planning period for the “National Plan for the Transport system 2010-2021”

The standard for maintenance of paved roads describes the road condition at which maintenance measures should be carried out. The standard covers both the functional condition, which is important for today’s clients of the STA, as well as the technical condition, which is important for the *durability* and therefor for tomorrow’s clients.

The objective of the maintenance standard is to serve a basis for assessment of maintenance needs on the national level, but also as a basis for identifying road sections/objects in need of maintenance measures.

The maintenance standard is given as limit values for a number of objectively measurable condition parameters. These parameters are IRI, rut depth, macro texture (MPD) and *edge height*, and are evaluated as mean values for 100 m (see also section 2.3.5). The standard levels for the 4 parameters is furthermore depending on traffic classes and posted speed limits.

However, only 60% of the total need for maintenance measures is estimated to be described by the objectively measured condition. The reason for a maintenance measure and the length of a maintenance section/object can be influenced by also other factors than the road surface condition:

- Measures can depend on damages that are not measured (e.g. cracks. Today cracks are monitored by visual inspection, but automatic methods are being developed.)
- Requirements from different stakeholders (and their concerns for traffic safety, environment, etc.)
- Preventive maintenance (to obtain lower life cycle costs)

- Realistic maintenance objects (It is seldom economically justifiably or practical to establish road works for too short sections)

The requirements for IRI and rut depth according to the maintenance standard are shown in the tables below. There are corresponding tables for MPD and edge height.

Table 12 Requirements on IRI-values in mm/m based on traffic and posted speed limit (mean values for 100 m)

Traffic (AADT)	Posted speed limit (km/h)							
	120	110	100	90	80	70	60	50
0-250		≤4,3	≤4,7	≤5,2	≤5,9	≤6,7	≤6,7	≤6,7
250-500		≤4,0	≤4,4	≤4,9	≤5,5	≤6,3	≤6,3	≤6,3
500-1000		≤3,7	≤4,1	≤4,5	≤5,1	≤5,8	≤5,8	≤5,8
1000-2000		≤3,0	≤3,3	≤3,7	≤4,2	≤4,8	≤5,2	≤5,2
2000-4000	≤2,4	≤2,6	≤2,9	≤3,2	≤3,6	≤4,1	≤4,9	≤4,9
4000-8000	≤2,4	≤2,6	≤2,9	≤3,2	≤3,6	≤4,1	≤4,9	≤4,9
>8000	≤2,4	≤2,6	≤2,9	≤3,2	≤3,6	≤4,1	≤4,9	≤4,9

3.1.6.2 Indicators and degradation models used for maintenance measures

IRI and Rut depth (max) are used throughout the transport administration to monitor condition on both network and local levels. The other performance indicators previously described are used for object selection or on object level. Linear extrapolation models are generally used and found acceptable. Mean profile depth (MPD) is an exception and a major effort has recently ended in models for prediction of MPD.

4 Relationship between pavement condition and applied interventions

4.1 Introduction

Pavement management systems are adjusted to specific conditions of a country – e.g. characteristics and extent of road network, climate, administrative and business arrangements.

A new road is constructed according to the standards, traffic loads and road design demands. Since pavement physical condition changes in time maintenance works are necessary when a conditions reaches a certain level. Even if the road condition improves to the initial state of an new road, there is usually still a deficiency regarding road design (number of lanes, curvatures, noise protection etc, and bearing capacity due to increase of traffic loads).

4.2 Austria

4.2.1 Inventory of maintenance measures and strategies and their effects on KPI

There are three overall types of intervention:

- general maintenance (H),
- repair (I) and
- renewal (E).

The measures listed in the Table 13 belong to one of these types (H/E/I) and are only suitable for one of three possible areas of application:

- interventions on road surface (O),
- interventions on pavement (D) and
- interventions to improve the load-bearing capacity (T).

Table 13 Types of maintenance intervention

Maintenance intervention (abbreviated name)	**Description/(Type H/I/E)**	**Application (O/D/T)**	**Characteristic affected by intervention**	**condition after intervention (%)**
0	No intervention			-
1 (FL)	Patching (H), local repair of damages	D, T	cracks, surface damage	ZG_{RI} = 0%, ZG_{OS} = 0%
2 (FR)	Milling of road surface (H) to reduce rutting or improve skid resistance	O	rutting, skid resistance	ZG_{SR} = 0 mm, ZG_{GR} = 0.8
3(BP)	Changing the concrete plates (H)	T	cracks, surface damage	ZG_{RI} = 0%
4(OB)	Adding a thin surface layer to the existing	O	rutting,	ZG_{SR} = 0 mm,

	pavement (I)		skid resistance, longitudinal evenness, cracks, surface damage	ZG_{GR} = 0.8, ZG_{LE} = 0.5 m/km, ZG_{RI} = 0%, ZG_{OS} = 0%
5(DE)	Renewal of road surface (I) by milling the old pavement and applying a new bituminous layer	D, T	rutting, skid resistance, longitudinal evenness, cracks, surface damage	ZG_{SR} = 0 mm, ZG_{GR} = 0.8, ZG_{LE} = 0.5 m/km, ZG_{RI} = 0%, ZG_{OS} = 0%
6 (VT)	Strengthening the subgrade (I) by milling the pavement and part of the base grade and replacing it with new material	T	rutting, skid resistance, longitudinal evenness, cracks, surface damage	ZG_{SR} = 0 mm, ZG_{GR} = 0, ZG_{LE} = 0.5 m/km, ZG_{RI} = 0%, ZG_{OS} = 0%
7 (AS)	Renewal of the entire superstructure (E) for asphalt roads	T	rutting, skid resistance, longitudinal evenness, cracks, surface damage	ZG_{SR} = 0 mm, ZG_{GR} = 0.8, ZG_{LE} = 0.5 m/km, ZG_{RI} = 0%, ZG_{OS} = 0%
8 (BE)	Renewal of the entire superstructure (E) for concrete roads	T	rutting, skid resistance, longitudinal evenness, cracks, surface damage	ZG_{SR} = 0 mm, ZG_{GR} = 0.8, ZG_{LE} = 0.5 m/km, ZG_{RI} = 0%, ZG_{OS} = 0%

Which area of application to use is determined from a technical and not an economical perspective: e.g.

- O when (ZWGR > 3.5 and ZWGR <= 3.5),
- D when (ZWGR > 3.5 and ZWGR > 3.5) or when (ZWGR <= 3.5 and ZWGR > 3.5) or when (GIKomfort >3.5), etc.

Depending on the intervention, the absolute values of the 5 pavement characteristics (rutting, skid resistance, longitudinal evenness, cracks and surface damages) are improved.

4.2.2 Estimation of maintenance costs

$$\mathbf{GK_{m,t,j} = EP_m \cdot Länge_j \cdot Breite_j \cdot AF_j \cdot (1+i/100)^n \text{ where } n = t - t_0}$$

$GK_{m,t,j}$ …… Total cost of intervention m on road section j at time t

EP_m …… Unit cost of intervention m (e.g. €/m^2) as determined by respective infrastructure operator

$Länge_j$ …… length of section j [m]

$Breite_j$ …… width of section j [m]

AF_j …… factor of influence (1 when intervention affects the entire area, otherwise the relative area of damage)

i …… inflation rate [%]

t …… time of intervention [YYYY]

t_0 …… begin of analysis [YYYY]

For interventions VT and AS explained in table 13 above (interventions on subgrade) the unit costs of strengthening or renewing the asphalt layers depends on the thickness of the applied layers.

$$\mathbf{EP_{VT} = (EP_{VT,12}/29.7)\cdot(4.5+2.1\cdot D_{Verstärkung})}$$

EP_{VT} …… Unit cost for strengthening of subgrade or partial renewal of subgrade [€/m^2]

$EP_{VT,12}$ …… Unit cost for strengthening of subgrade or partial renewal of subgrade, where strengthening thickness = 12 cm (pavement + bituminous bound road base) [€/m^2]

$D_{Verstärkung}$ …… Thickness of strengthening [cm] NB: this is an example of how the degree of degradation determines the cost of maintenance, as the thickness of the additional strengthening depends on the extent of wear.

$$\mathbf{EP_{AS} = (EP_{AS,\,LK\_S}/51.0)\cdot[1+2\cdot\,(2.8289\cdot \ln(BNLW)\,\cdot 1000000)-23113]}$$

EP_{AS} …… Unit cost for renewing asphalt road [€/m^2]

EP_{AS,LK_S} …… Unit cost for renewing asphalt road to suit load class S according to Austrian guideline RVS 03.08.63[€/m^2]

BNLW …… Load cycles for design calculation according to RVS 03.08.63 [million]

4.3 Belgium

4.3.1 Inventory of maintenance measures and strategies and their effects on KPI

There will be 9 type of maintenance described in the PMS developed by the Flemish Region.

If we consider other maintenance tools that exist and/or are developed in Belgium, we can also mention the software ViaBEL. This pavement management system is issued form the collaboration between BRRC and KOAC-NPC. This tool includes different maintenance strategies for communal road networks.

Different maintenance strategies are implemented in ViaBEL. Each strategy is defined according to the maintenance measures that it includes. The maintenance measures are: routine maintenance, local repairs, generalised repair, reinforcement (thickening), a complete rebuild. Based on this gradation of measures, we can mix them and develop multiple scenarios following the various management practices. Three options are proposed for asphalt surface generalised repairs (single surface dressing, double surface dressing, thin overlay) but for cement concrete the model proposes the replacement of the slab or the damaged area. Two options are proposed for reinforcement, these are based on the thickness of the layer : variant 1 takes a 6cm layer into account, variant 2 a 12cm layer for asphalt and a pavement replacement for cement concrete.

Eighteen scenarios are then proposed, from zero undertaken measures to the best practices.

Table 14 Maintenance strategies

	Strategies																	
Strategy	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Routine Maintenance	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Local repairs	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Generalised Repair																		
Variant 1							x	x	x						x	x		
Variant 2				x	x	x								x		x		
Variant 3	x	x	x										x		x			
Reinforcement - Thickening																		
Variant 1			x			x			x			x						
Variant 2		x			x			x			x							
Rebuild	x			x			x			x								

The gradation between the three kinds of measures (local repair, generalised repair, reinforcement) is driven by threshold reached by the visual index.

Table 15 Threshold of the visual index

Visual Index	Repair option
0.9	Routine Maintenance
Threshold S1	Local Repairs
Threshold S2	Generalised Repair
Threshold S3	Reinforcement - Thickening

When a simulation is launched with ViaBEL, the operator may opt for a strategy that is coherent with the habits and the specific socio-economic situation but may also run other strategies and evaluate the impact on a quality and on budget point of view. For example, what will be the situation in ten years if there is a total lack of measures? Will a scenario based on the “best measures” bring a significant improvement on the network or on a specific section? Will the return on investment be significantly increased by this “best measures”?

4.3.2 Estimation of maintenance costs

For the PMS developed by the Flemish region, the costs are described in function of the maintenance type and not in function of the deterioration level. The unit is the square meter for the pavement or the cm (height) per m² for the deeper layers. If the cost is based on the surface, the cost will take into account the type of lane for multiple lanes roads (eg : emergency, first lane for HGV and other lanes). The social costs are not taken into account at this time.

At present, the priorities are set by the central administration and are based on the different performance indicators. The road sections in need of attention are then communicated to the different road districts where the most appropriate techniques are selected based on further investigation and measurements if needed (for example: based on coring, deflection measurement, …). Budgets are proposed to the central administration based on these investigations. In the future, the PMS (as described) will include an economic module.

For the afore mentioned software ViaBEL, specific for communities road networks, we can describe how the costs are estimated to maintain the network. ViaBEL integrates a financial module. The average costs for each of the measures are included and can be modified given the situation of the network (proximity of a production center, accessibility, regional economic situation…). ViaBEL is a network based assessment program, for this reason the costs are average ones and are not related to specific project costs even though those can be fine tuned in order to represent the most realistic situation.

An economical model is also included in order to propose the best moment to perform a given maintenance. This is combined with the evolution law to allow the user to influence the decision making process. The model is based on the Terborgh method and takes into account the maintenance and the repair measures. The evolution of these two costs centers are amortized annually.

The model considers that annual maintenance costs "c" will follow a geometrical progression with a "σ" rate. The annual depreciation rate is "r" and the indexation is "i". The maintenance cost at time "t" is

$c_t^{ent} = c \cdot (1+\sigma)^{t-1} \cdot (1+i)^{t-1}$ and the total discounted cost over T years is $C_T^{ent} = \sum_{t=1}^{T} c_t^{ent} \cdot (1+r)^{-t} + C_T^{repair} \cdot (1+r)^{-T}$.

The maintenance and repair costs are annually spread with the help of the

Capital Recovery Factor : $CRF = \frac{r \cdot (1+r)^T}{(1+r)^T - 1}$.

The model then computes the minimum of the summed costsand this gives the best economic moment to perform the repair. This method is combined with the index thresholds from the evolution laws to determine the best moment to allocate the resources. The Figure 13 represents the evolution of the annually discounted repair and maintenance costs, the repair costs follow a logical increase annually and the annuity to constitute the repair budget is a decreasing function of time. The Terborgh method is described in Delaunois, 1988.

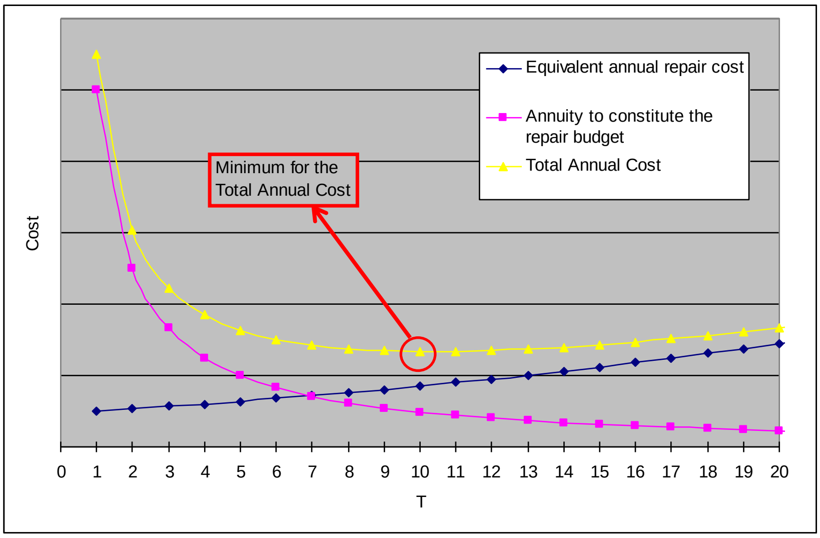

Figure 13 The evolution of the annually discounted repair and maintenance costs

The model gives the theoretical date (year) when the repair should best occur in order to minimize the budget. If the evolution law goes beyond one of the maintenance thresholds (S2 or S3) before this date is reached, the repair will be triggered in the planning. The model also includes budget boundaries. The maintenance and repair operations are conducted within these limits.

4.4 Croatia

4.4.1 Inventory of maintenance measures and strategies and their effects on KPI

The possible repairs depend on type of the structure and can be grouped into:

- Regular maintenance;
- Preventive maintenance;
- Rehabilitation;
- Reconstruction.

From the performance indices (i.e. technical parameters according to which they are calculated) homogenous sections with type repairs and costs are determined.

4.4.2 Estimation of maintenance costs

Finishing the era of intensive road (especially motorways) construction in Croatia, maintenance of newly built asset will become primer activity of all road authorities. State legislative has set guidelines for systematic management, by laws and regulations which define plans for construction and maintenance of public roads through strategy and program for construction and maintenance. Strategy sets up goals and plans of public roads development and, among other, it comprises condition analysis and proposal of priority lists, as well as needs and principles of existing roads maintenance. Program of construction and maintenance is, in accordance with Strategy, adopted for four years planned period, and is generated through yearly plans prepared by companies and authorities in charge of construction and maintenance of roads.

The pavement and pavement infrastructure management activities are enabled through, for this purpose designed, management systems. A road infrastructure management system, with the purpose of managing the structures administrated by the company Croatian Motorways Ltd., is being developed by IGH Institute Inc, Zagreb, Croatia. The system includes all structures that are part of a motorway: bridges, geotechnical structures, pavements, tunnels, drainage, road equipment and buildings. At this moment, the model for pavements is in development and should be in practice till summer of 2012. The estimation of the maintenance cost is being currently under development.

Data collection is carried out according to the procedures described in chapter 2.3.3. Data collected by the measurements is stored directly to Pavement management system base, manually or in automated procedure, using compatible digital format.

Homogenous sections, suitable for one of typical repairs, are determined from the performance indices and costs for maintenance are calculated. They are the baseline for multi-year planning and preparation of the optimal maintenance strategy.

The curve of the structure condition degradation as a function of time will fall within the area that defines which maintenance methods to apply (routine or preventive maintenance, rehabilitation or reconstruction). The priorities and different maintenance scenarios are calculated for a planned period, on the basis of the present and predicted future conditions. The optimal scenario of costs and structure condition is than chosen.

4.5 Netherlands

Pavement management system in the Netherlands is addressed by 'Meerjarenplanning verhardingsonderhound 2006-2012' [12]. The content of the Multi Year Road maintenance Planning, Road district from Haaglanden (Netherlands) report is summarized below.

The administration RWS (Rijkswaterstaat, Environment and infrastructure Office) is in charge of the management and maintenance of the road network. Given A basic quality level (called BON, see literature chapter : G reference 15), it is needed to answer to the following : where, when and which maintenance should occur and what will be the costs. In order to be able to give these answers, the road network quality is monitored on a yearly basis with a MJPV (multiyearly pavement maintenance plan). The MJPV is adapted every two years following the results of the measurements. The MJPV is refreshed yearly with the completed maintenance and with visual inspections.

A system called IVON is used to build the MJPV. IVON is fed with the following data:

Network: length and width

Pavement: layers (year and type) with actualisation from visual inspections (ARAN and inspectors)

Quality: Rutting, Evenness, Roughness, Cracks and crazing

Based on this and on a ranking for the roads, a draft is issued by IVON for a planning. This is evaluated on site by inspectors and adapted for the next 5 years with the different road districts.

The MJPV is not considered as a project level tool.

The maintenance measures are classified in two types : large scale maintenance and maintenance aimed for lifecycle prolongation. Large scale maintenance includes : repair of the pavement, addition of an extra intermediate layer (reinforcement), addition of a new pavement layer. Life cycle prolongation is performed where safety levels are not involved.

A description of IVON software is available.

The report is mostly the presentation of the MJPV for the period 2002-2006. The appendices are in the Part 6 (bijlagen) and can be interesting for the project.

A – outputs and ranking for the IVON software

C – Maintenance measures: classified in two types (reconstruction or maintenance to extend the service life)

D – description of IVON software

G - literature

4.6 Slovenia

In 1994 only 139km of motorways were built in Slovenia. From 1995 to 2009 a large motorway network has been built which in 2011 consist of 528km of motorways and express ways. The pavement are generally flexible, except from in tunnels, where the cement concrete pavement were built in. DARS –the Motorway Company in the Republic of Slovenia is in charge of and responsible for building and maintaining the motorway network. Since the length of motorway network increased significantly in the last fifteen years, it was decided to implement a Road Management System (RMS) on the motorway network. The pilot project started in 2002 and data base of existing network was established and gradually supplemented.

The pavement management system (RMS) includes three types of treatments – 'Major treatments', 'Minor treatments' and 'Ancillary treatments' as defined in chapter 4.3.5. Three types of variables were defined to model the degradation of the road network

- Dynamic analyses variables (they change after maintenance tretmanes)
- Annual analyses variables (they change every year – eg. age of pavement)
- Attributes (e.g. locations)

Degradation models, described in the preceding chapters are used for assessing

- MSI – pavement surface distress (surface damage)
- Longitudinal evenness
- Rutting - Transverse evenness
- Skid resistance

Based on these technical parameter, the dimensionless performance indices are calculated, which are dimensionless. The performance indices have values from 0 to 5, where 0 means very good and 5 means very bad condition. The correlation between performance index for transverse evenness and road condition is shown in Figure 14.

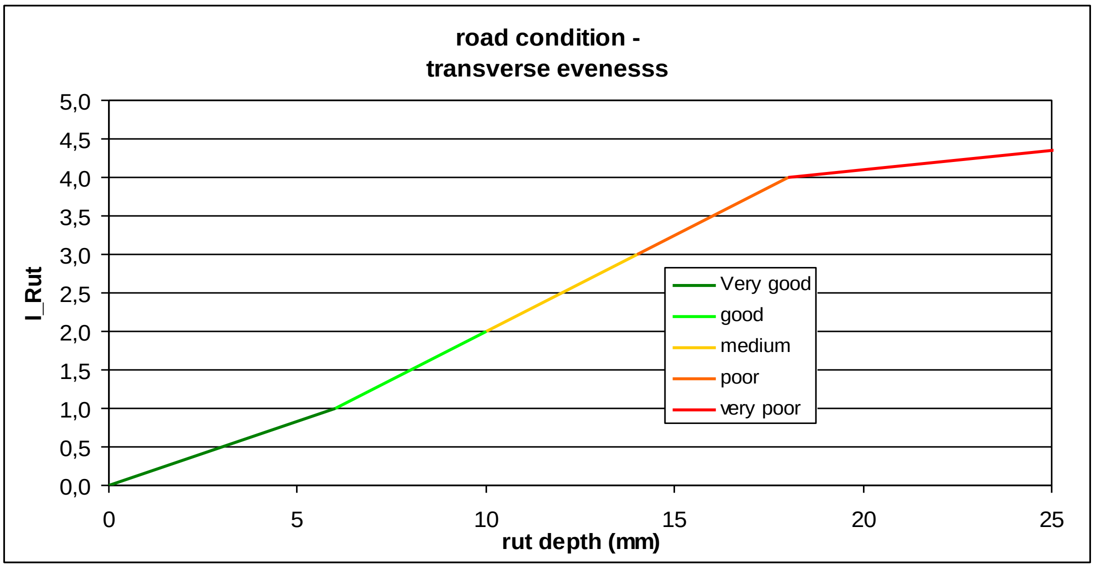

Figure 14 Road condition regarding transverse evenness

The results of the Pavement management system (RMS) enable the user to estimate the needed funds for maintaining the road in preferable condition on the network level. It enables the road manager to

- look into the future of the road network with relation to different scenarios according to available funds,
- determine the consequence of the maintenance negligence and
- make the maintenance plan for the analysed period, taking into account the budget limitations.

The system currently implemented is used only on the network level and for a short period of time. It takes into account pavement condition on an operational and effective manner. For other parameters, such as condition of road equipment, condition of retaining structures (anchored walls, large embankments), condition of subgrade (bearing capacity, dewatering), traffic loads are not taken into account. Measures to improve environmental issues – like construction of noise barriers are also not based on measured and monitored parameters.

4.6.1 Inventory of maintenance measures and strategies and their effects on KPI

The pavement management system currently used on the network level for motorway distinguishes three types of treatments:

Major treatments: in a one year time–period, only one ‘Major treatment’ can be carried out on one road section. Maintenance actions such as strengthening, overcovering, local rehabilitations and reconstruction of pavements are considered as major treatments.

Minor treatments: several minor treatments (patching etc) can be carried out in one year time on the same road section.

Ancillary treatments: additional, usually minor treatments

A catalogue of the maintenance measures was formed which includes.

- local repair of damages - patching

- surface dressing - adding a thin surface layer to the existing pavement
- reshape - milling of a road surface to reduce rutting or improve skid resistance
- repave -renewal of a road surface by milling the old pavement and applying a new bituminous layer
- reconstruction of pavements - strengthening the subgrade and the asphalt superstructure.
- strengthening, - renewal of the entire superstructure

For these above listed measures the costs were estimated and the trigger values were defined for motorways. Since the system is not implemented for a long period of time, there is available only limited practical experience on the effects of the maintenance measures on the performance indices.

4.6.2 Estimation of maintenance costs

For the maintenance measures defined in the pavement management system, costs can be defined and updated.

4.7 Sweden

4.7.1 Inventory of maintenance measures and strategies and their effects on KPI

Maintenance measures and their influence on performance indicators have been subject to studies and some information is available. However, the difficulties involved in predicting the success of maintenance differ for each indicator. For example, while macro texture is a result of the surface properties of the applied material, influence on longitudinal profile and evenness is a result of a number of equipment and treatment option alternatives. Software has been developed to simulate effects of different maintenance options. In practice, pavement engineers rely on expert judgment to select the optimum maintenance strategy. There is a knowledge base to rely on such as a handbook for treatment selection.

A survey among different regions showed that the maintenance strategies varied between the regions. There are reasons such as differences in climate, market density and materials but also a lack of knowledge and consensus regarding the best strategies. Selecting the optimum treatment is not just a matter of improving KPI/PI in the short run but also to spend limited funds wisely (budget constraints) and foresee the next maintenance measures and their consequences in terms of road manager and societal costs. Therefore, suggesting values or models to predict improvements in terms of KPI/PI should be done with caution. Another aspect that has been evident from Swedish attempts is the difficulties involved in using statistical values on KPI/PI improvement. Historical evidence can be used for prediction if the conditions are similar in terms deterioration mechanisms and maintenance history. However, statistics can be misleading if information on individual objects are missing or not filtered for. For example, a surface dressing may show extremely good performance with respect to rut development, while the true reason might be a historically excellent bearing capacity resulting in no need for more than a surface treatment on the particular section.

4.7.2 Estimation of maintenance costs

Life cycle modeling as a decision making tool in pavement investment and management is currently under development. The principle is to derive estimated prices and future performance and service life separately and then estimate total life cycle cost. At the same time, environmental considerations should be taken such as the estimated total energy needs.

Price information is continuously collected from procurements. A model has been developed for estimating calculation prices for different maintenance alternatives, which is based on a material part, a transport part and a production part.

Societal costs are often taken into account, especially regarding time delays and noise. One tool has been developed to consider environmental costs such as noise and particle emissions, based on the Swedish catalogue for assessment and valuation of societal costs, and compare them to the life cycle cost of wearing course designs. Another tool has been developed to estimate time delays for road works, which is based on micro-simulation of typical road work designs.

The overall PMS consists of a number of modules used in different stages and levels. The levels can be divided in:

- Network (strategic) level where road conditions are monitored and funds allocated
- Programming and Planning level where object candidates are selected
- Object level where treatment design is performed

The overall framework for PMS presented in the Table 16. The system is currently redesigned but the framework will not change.

Table 16 Principle of the Swedish PMS framework

Data sources	***Data production***	***Output utilities***
Road surface monitoring data		Information on maps
Maintenance database		Numerical info by region
General road network data		Numerical info by road link
	Database PMS	Visual and numeric data by section
		Extraction of maintenance candidates
		Historical parameters
		Data mining and extraction

The general road network data (NVDB) is common for several services and utilities provided by the Transport Administration to the public, service providers and companies. NVDB contains data such as location, road type, wearing course type, traffic, road identity, regulations (speed limit, restrictions, bearing capacity) and road manager. The maintenance database contains data such as type of wearing course (details), type and date of maintenance measures that are tied to sections on roads. Road surface monitoring data is stored in accordance with the previously described data collection procedure.

For strategic planning on network level there are utilities to present data region by region, per road category etc., for example applying historical data to threshold levels to see how the road condition is developing. Visual tools are also developed in which users can access data on maps such as general road network data (NVDB) and condition parameters rut depth and IRI. The last example is accessible for public use at http://gis.vv.se/iov/.

Object selection and maintenance planning is facilitated by a module where performance indicator thresholds can be set and the filtered sections can be presented by list or on a map.

PMS data is extracted and presented in an access database with a PC software interface ("Väggrafen"). The database include data from the three data sources described above for all homogenous road sections on the national road network, but also a few more calculated parameters such as mean, min, max and 90-percentiles for rut depth and IRI per homogenous section. The data also include mean values for every year per homogenous section for the whole network.

There have been attempts to synchronize treatment selection and design process into an object design tool. The current tool for pavement design ("PMS Objekt") can be used for structural aspects of pavement maintenance design. However, no overall system is implemented for optimization of maintenance treatments on object level, but several efforts are undertaken. Sweden was early involved in the development of HDM and other initiatives which led to substantial knowledge that can be integrated into PMS on object level. Object level decision support of today consists of various tools, documents and specifications.

4.8 Conclusions

From the Pavement Management Systems developed and used by different countries, we can conclude that they are often based on the same principles. We have here examples from the Netherlands, Belgium, Austria, Croatia, Slovenia and Sweden. The terms used for the different interventions may slightly vary from one description to another but the philosophy is comparable. It is important to accurately define an intervention level: a maintenance intervention in one PMS can be defined as a repair in another.

The pavement condition is qualified with technical parameters issued from terrain measurements and are related to the rutting, the surface evenness, the roughness - or skid resistance - and a visual parameter. This last parameter is an indicator of the pavement surface and relies on visual inspections. Different methodologies are developed and applied for these inspections and they range from a global assessment based on a qualitative approach to extremely detailed inspections performed with highly automated equipment and detection devices.

The interventions are classified following their goal: Maintenance, Strengthening and Reconstruction. Maintenance interventions are performed in order to keep the service quality in conformity with the design of the road and maintain the service life as designed. Maintenance measures may vary following the envisaged PMS. Maintenance will not improve the service life but will "maintain" a conform condition. Other measures will have a positive effect on the Service life and the final solution being a new road with a reconstruction – rebuild.

PMS may be limited with the number of measures included in the model. Some models are very detailed as IVON (The Netherlands) and other may include more general types of interventions because they are designed to provide management guidelines at a higher level.

The degree of detail for the different measures is also a function of the organization of the NRA and how the decision making process (technical solution, budget …) is organized within a NRA (presence of local districts …).

The costs are directly related to the detail level in the PMS: types of maintenance included in the model and detail level of these. Average costs are always included; they are given per unit of area.

5 Relationships between asset condition and end user service levels

5.1 Example: Austria

The following performance indicators are measured regularly on the Austrian primary road network. The suggested interventions/measures are mentioned in the Austrian Pavement Management System (PMS) Handbook, along with the values to which the performance indicators are restored after a certain intervention is implemented. Each measure belongs to one of the following groups: **maintenance, repair, renewal**

Table 17 Relation between measures and Performance indicators

Asset	Performance Indicator (PI)	Type of measure	Technical measure	Value of PI after applying the measure
Pavement	1. Rutting [mm]	Maintenance	Milling	0 mm
		Repair	Applying a thin surface cover	0 mm
			Renew surfacing	0 mm
			Strengthening substratum and renewing surfacing	0 mm
		Renewal	Asphalt/concrete superstructure renewal	0 mm
	2. Longitudinal evenness [m/km]	Repair	Applying a thin surface cover	0.5 m/km
			Renew surfacing	0.5 m/km
			Strengthening substratum and renewing surfacing	0.5 m/km
		Renewal	Asphalt /concrete superstructure renewal	0.5 m/km
	3. Cracks [%]	Maintenance	Patching	0 %
			Changing concrete blocks	0 %
		Repair	Applying a thin surface cover	0 %
			Renew surfacing	0 %
			Strengthening substratum and renewing surfacing	0 %

		Renewal	Asphalt /concrete superstructure renewal	0 %
	4. Surface damage [%]	Maintenance	Patching	0 %
			Changing concrete blocks	0 %
		Repair	Applying a thin surface cover	0 %
			Renew surfacing	0 %
			Strengthening substratum and renewing surfacing	0 %
		Renewal	Asphalt /concrete superstructure renewal	0 %
	5. Skid resistance [1]	Maintenance	Milling	0.8
		Repair	Applying a thin surface cover	0.8
			Renew surfacing	0.8
			Strengthening substratum and renewing surfacing	0.8
		Renewal	Asphalt /concrete superstructure renewal	0.8

Each of these performance indicators is normalized to give dimensionless index values, which in turn are combined by equations (weighting factors) to give certain **indices (value 1 – 5)** that describe the pavement condition. These indices are: structural index for surface condition, serviceability-safety index, serviceability-driving comfort index and load-bearing capacity.

The Table 17 illustrates what normalized values contribute to what index (weighting factors and equations for combining the values not shown). The equations linking the normalized performance indicator values and the indices are empirical and based on a large dataset of parameters measured over several years on Austrian roads.

For primary roads, there is an empirical-deterministic function in the Austrian PMS Handbook to predict the development of each performance indicator over time i.e. showing future degradation. This means that the condition indices can also be plotted as a function over time i.e. the serviceability and structural index can be predicted.

5.2 Example: Belgium

Both the Flemish Road Administration and the Walloon Road Administration inspect some road surface characteristics on a regular basis on their part of the primary road network of the country. For each of the inspected road surface characteristics they transform the measurement data into individual surface characteristic indices and classify the road sections for each of the characteristics separately. Both administrations also combine the individual surface characteristic indices into a combined indicator and classify the road sections based upon this combined indicator.

In Flanders, the following parameters are measured:

- skid resistance
- rut depth (for asphalt road surfaces)
- stairs (for concrete road surfaces)
- longitudinal evenness
- level of surface deterioration (cracks, stripping, distress at the edge of the road,…)

Skid resistance is measured by the SCRIM and expressed in side-way force coefficient. Rut depth, stairs and longitudinal evenness are measured by the ARAN. The level of surface deterioration is based on visual inspection from images taken by the ARAN and its crack detection module.

The parameters are usually measured on the “slow lane” only since this is also the lane of the road used the most by heavy traffic. Usually it is also this lane that needs most maintenance attention.

For each of the defects, an individual index is computed (without unit, values between 0 and 100).

There are five categories of quality: class A (index ≥ 80) “very good”, class B (80 > index ≥ 60) “good”, class C (60 > index ≥ 40) “sufficient”, class D (40 > index ≥ 20) “bad”, class E (20 > index) “very bad”. When a threshold is reach for one of the individual indices, the state of the road section is labelled “insufficient” (usually the threshold is 40). Priority for maintenance is set to those road sections labelled “insufficient” for rutting or skid resistance since these parameters have a direct influence on the safety of the road users. Priority is also set by the absolute value of the individual index: the road section with the worst insufficiency is treated first.

In order to choose the most appropriate maintenance intervention for a particular road section, a more detailed investigation aiming at the determination of the cause of the state of road section is needed since the measurement data used for the Pavement Management do not give enough information for such a decision. For instance, the bearing capacity is not evaluated at the management level but should be taken into account before the execution of main

In order to evaluate the “functional performance” of the road network, another treatment of the measurement data is used in addition. For this, three functionalities are considered: safety (expressed by a combination of skid resistance and rutting), comfort (expressed by evenness) and structural integrity (expressed by the visual inspection of the road surface).

For the “functional performance”, other classes are defined and different threshold are used for motorways, primary or secondary roads. As soon as one of the indices reaches its threshold for a lower quality class, the road section is labelled with that lower quality.

In the Walloon region, the following parameters are measured:

- skid resistance
- rut depth (for asphalt road surfaces)
- longitudinal evenness

The SCRIM is used for skid resistance, the TUS is used for rut depth and the APL is used for longitudinal evenness. As in Flanders, an individual index is computed for each of the defects (without unit, values between 0 and 100) and there are five categories of quality. The obtained values are put on maps. A combined indicator is defined as a weighted sum of the individual indices for evenness, skid resistance and rut depth, computed and put on a map as well.

5.3 Relationship between skid resistance and driver safety

There is a lot of knowledge regarding the relationship between skid resistance and crashes. The studies have shown considerable reduction in wet-weather crashes following resurfacing which improves skid resistance. But the evidence regarding the effect of improved skid resistance on dry weather crashes is mixed.

Most of the pavement maintenance systems and the threshold values that trigger maintenance measures are based on results of regular monitoring of skid resistance, which is usually an important factor in maintenance measure planning.

Monitoring programs and maintenance systems can be based on identifying sites with low skid resistance and large numbers of wet-weather crashes. With prompt maintenance measures the safety level of drivers may be significantly increased on these road sections. But to increase the driver safety and deliver higher crash reductions in general many other factors will absolutely have to be taken into account.

Studies undoubtedly show that the proportion and/or rate of wet weather accidents increases as skid resistance diminishes, but studies disagree on the type of the relationship and its strength. For example: in an re-analysis of one Australian study it was estimated that a benefit-cost ratios for surface treatments were at between 15 and 84:1, depending on the type of treatment, which was between four and seven times the benefit-cost ratios estimated in the original study. This shows that similar studies are very sensitive to the known and quantitative and unknown factors.

Therefore it is obvious that many other factors than skid resistance must be taken into account when driver safety in general is discussed. One also has to consider:

- road condition - longitudinal evenness and rut depth and cross-fall (all these factors influence dewatering),
- traffic flow (average daily traffic),
- traffic speed and type of road (one lane, two lane road)
- horizontal curvature,
- gradient,
- road equipment – barriers, lighting, markings etc
- crash type (overtaking, head on, lost control, rear end, not taking into account crashed due to alcohol-impaired drivers),
- social factors (type and age of vehicles, driving habits etc).

For illustration: According to 2009 drunk driving statistics, there were 33,808 fatalities in the US, from which 12,744 alcohol-related fatalities. 10,839 fatalities in crashes involved a driver with a Blood Alcohol Concentration (BAC) of 0.08 g/dL or higher. That represents 32% of total traffic fatalities for the year 2009. The remaining fatalities consisted of 2,891 (27%) motor vehicle occupants and 667 (6%) non-occupants. The rate of alcohol impairment among drivers involved in fatal crashes in 2009 was four times higher at night than during the day (37% versus 9%). In fatal crashes in 2009 the highest percentage of drivers with a BAC level of .08 or higher was for drivers ages 21 to 24 (35%), followed by ages 25 to 34 (32%) and 35 to 44 (26%).

Within a decision making framework the parameter on skid resistance has to be combined with other factors regarding road condition, moreover an engineering judgement is needed for optimised maintenance planning. When skid resistance level falls below a critical threshold value, maintenance measures are necessary. Guidelines regarding what factors should be taken into account, apart from the skid resistance, should allow for engineering judgement to plan minor maintenance actions (e.g. resurfacing) or to plan major reconstruction of a road section including changes in road layout etc.

Based on numerous researches it can be concluded that adequate skid resistance of pavement is very important for the end-user because skid resistance is related to braking distance and skid-related crashes, particularly wet weather crashes, but it is very difficult to quantify the relationship since it is site specific and influenced by a number of factors other than skid resistance.

6 Conclusions

A road network, like any major asset, has a number of individual and distinct components that degrade and need to be repaired. For highly trafficked roads, it is important to maintain the pavement in good condition and to minimise the closure of lanes in order to keep the end user service levels (EUSL) at the expected level. From an asset management point of view, the components of greatest interest are those that are key contributors to performance or to the satisfaction of stakeholder needs, then the components that are most prone to deterioration or need ongoing management, and finally the components that are the most expensive (in terms of life cycle costs).

The basis for every Pavement Management System (PMS) is an extensive database. Depending on the quality and amount of data gathered and the suitability of the models used to analyse these data, the economically most effective actions can be taken. The databases need to be open and flexible, so that new or more refined parameters can be included into them. Since environmental awareness increases, it will become necessary to include parameters on noise, pollutants (PM_{10} and NO_2 concentrations or the discharge of polluted splashing water) or perhaps the negative influence of the road layout on the landscape. A database has to enable data exchange with other databases, archiving and user-friendly updating of the data.

Predicting pavement condition in the future requires the acquisition of the current condition of road assets and models to predict degradation in time. Many tools exist to acquire the parameters describing the condition of pavements, but few degradation models have been employed in practice in pavement management. For application of PMS we need

- Inventory data - general road network data,
- Road condition monitoring data,
- A maintenance database.

The network referencing system can be arranged in different ways – many parameters such as the class of road, the road number, road section, chainage and inventory data such as the width of lanes, traffic loads, structures, footways, layout, curvatures, crossings must be taken into account. Every country has built a road database in its own, specific way. It is obvious that different databases for pavement management systems are not easily compatible.

The design of pavements and materials used for road construction differ throughout countries, as well as the climate conditions. This is why degradation models for pavements must differ, yet the pavement parameters measured to establish pavement condition do not differ a lot. Road condition monitoring is largely used in all countries for maintenance planning. It usually consists of road surface monitoring and road bearing capacity monitoring.

Road condition is evaluated in the form of the damage extent with respect to certain pavement characteristics. The pavement characteristics quantitatively and qualitatively describe pavement condition and can be physical values, indices or relative values. The characteristics apply to a certain length of road section and in many countries they are calculated by averaging over a 50 m or 100m long road section.

Maintenance databases should be updated regularly to inform the pavement manager of all maintenance measures taken – unplanned minor interventions as well as renewal of the entire pavement structure.

Another aspect of roads that should be considered in the PMS is the layout of a road section, i.e. its cross section (number of lanes), cross-traffic, dewatering etc.

Pavements play a major role in any road network and their existing management systems were investigated. A questionnaire handed out to road agencies aimed to find out what performance indicators the operators employ to measure the standard of the infrastructure, what interventions they use, as well as what the benefits of different management strategies are regarding end-user service levels. Feedback to the questionnaire was received from Austria, Slovenia as well as from Belgium, Croatia and Sweden. Most countries use a pavement maintenance tool, according to national specifications since there are no European standards. In many countries the pavement management system is being constantly improved and has not been used for a long time in maintenance planning.

In ASCAM an attempt has been made to establish the relation between the improvement of pavement characteristics, end user service levels and costs. The costs of construction works depend greatly on the location, length of section under repair, as well as the societal costs regarding time delays and noise. It is also difficult to economically evaluate the cost of change of driver safety during maintenance works etc. On the research level, tools have been developed to consider environmental costs such as noise and particle emissions, and compare them to the life cycle cost of wearing course designs. Tools have been developed to estimate time delays for road works and tools to optimize the road closures. A rough assumption of the costs can be given, but the value is related to the detail level of a PMS - that is which costs are taken into account. It is impossible to derive a long-term typical value of the costs for maintenance measures, so the data on costs must be constantly updated in the PMS.

We can conclude that relationships between maintenance measures, pavement condition and end-user service levels are not yet established in current practices. Research was done to quantify these relations but further attempts are necessary.

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