Actual Researches on the Austrian PMS-Sector

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SYNOPSIS

In 2001 the Austrian motorway company ASFINAG (Autobahnen- und Schnellstrassen-Finanzierungs-AG), in cooperation with the BMVIT (Federal Ministry of Transport, Innovation and Technology), and the ISTU (Institute for Road Construction and Maintenance, TU Vienna), started with the practical application of a computer-assisted PMS to harmonize systematic road maintenance and to improve the efficiency of maintenance strategies on Austria's 2000 km of motorways and expressways.
The institute's task is the development of new models and elements as well as the improvement of existing PMS components. Since practical application was started, a wide range of innovations and research has been carried out, which could be summarized as follows:

- Revision of the method employed for assessing pavement condition in cooperation with the road administration authorities (calculation of performance and structural sub-indexes and a combined condition index)
- Development of an algorithm and a software module for the generation of segments characterized by homogeneous pavement conditions using Bayesian statistics (cooperation with VTI, the Swedish National Road and Transport Research Institute)
- Improvement of existing and development of new performance prediction models (semi-probabilistic deterioration functions) for various pavement condition attributes by the using "Bayesian updating-process" (cooperation with the Institute for Statistics and Probability Theory, TU Vienna)
- Development of a section-based calibration method for performance models
- Development of a pavement structural number specifically for Austria to describe the structural entities of pavement structures
- Development of an additional PMS module for the integration of user costs into the optimization process

These models and components have been implemented in the PMS software package step by step since spring 2002 and will be presented in the paper.

INTRODUCTION

The increasing importance of Austria's high-level road network (motorways and expressways) at both the national and the European levels has led to a marked rise in traffic volume over the past decades and subjected road pavements to increased wear and tear. This is reflected, on the one hand, by a rise in the various types of pavement distress as well as by a significantly expanded need for structural maintenance work.

By implementing a computer-based Pavement Management System (PMS), the Austrian motorway company ASFINAG (Autobahnen- und Schnellstrassen-Finanzierungs-Aktiengesellschaft), in conjunction with the BMVIT (Federal Ministry of Transport, Innovation and Technology), took a first step in 1998 toward optimizing the allocation of the usually scarce funds provided in the budget for the maintenance of Austrian motorways and expressways (total length: about 2000 km). After a development phase of about three years (database and analytical tools), the system went operational in spring 2001.

In this context, the Technical University of Vienna's Institute for Road Construction and Maintenance is responsible for the development of new and the improvement of existing system elements as well as for field testing these PMS components in co-operation with road administrations. Since the system first became operational, a wide range of new basic research has been conducted and the results implemented in practice. The following paper will describe some of the most recent research findings in more detail.

OVERVIEW OF THE AUSTRIAN PMS

The system employed for systematic pavement maintenance planning is based on a procedure that provides a framework system for decision-making on maintenance measures in order to optimize efficiency in terms of the use of the resources available or in terms of pavement condition. The procedure employs benefit-cost analyses as well as a heuristic optimization process to identify the optimum maintenance strategy in a given set of conditions (budget or pavement condition). This system is applied to the entire network of motorways and expressways (network level). The different elements of the Austrian PMS are represented in Figure 1.

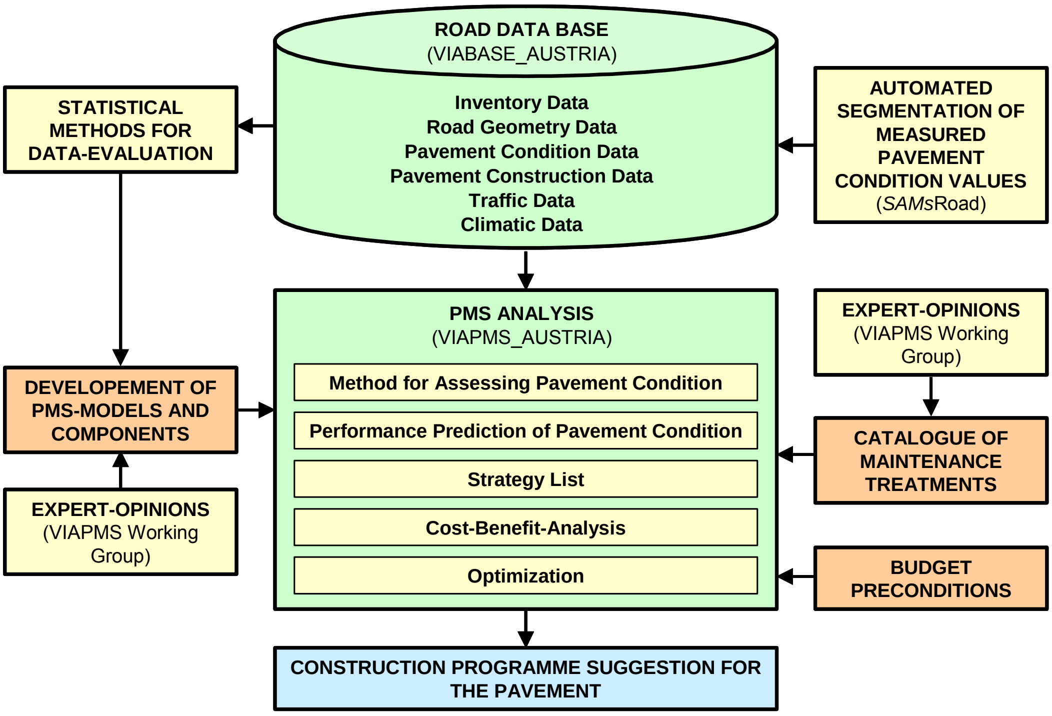

Figure 1 Elements of the Austrian PMS (schematic)

Information of relevance to pavement maintenance (pavement data, pavement condition data, traffic data, etc.) is managed using a Canadian commercial database system named VIABASE$^©$ (dROAD$^©$), which supports the flexible combination of data available on different road segments. This road database was specially configured to meet Austrian needs and is known as VIABASE_AUSTRIA (Weninger-Vycudil et al 2003b).

The data included in VIABASE_AUSTRIA in the format of coefficients and descriptive indexes are used to perform life-cycle analyses that can be used as a basis for identifying the optimum maintenance strategy. Analyses are performed using an open software system called VIAPMS$^©$ (dTIMS$^©$), which was likewise developed in Canada.

The result of an analysis is obtained in the shape of a proposal for an optimum maintenance strategy for each road section analyzed (as a function of the conditions defined), which can be used for further evaluation at project level. By aggregating section-based results, one can also assess developments in terms of cost and pavement conditions across the entire network level and, finally, determine the maintenance requirements in the road network being evaluated.

To obtain these results, the data and information being analyzed have to pass through a given algorithm, which consists of a variety of sub-elements. These sub-elements are of modular design and can be adapted or allocated quickly and easily as new insights are gained.

DEVELOPMENT AND IMPROVEMENT OF SYSTEM ELEMENTS

Once the first insights had been obtained from the practical implementation of the Austrian PMS on motorways and expressways, a number of improvements and additions were made to the system with the primary objective of increasing the accuracy of the results obtained. This involved PMS modules which were developed at the ISTU, mostly as part of research projects, or are still under development. These modules include:

- the review or modification of the method used for pavement condition assessment
- the development of an algorithm and a software module for the creation of road segments that are homogeneous in terms of pavement condition
- the improvement of existing and the development of new pavement condition prediction models
- the development of a method for the section-based calibration of deterministic performance functions
- the development of an “Austrian Structural Number” to describe the structural status of flexible pavements
- the development of a module introducing user costs into the analysis

The results of these studies have been implemented in the system step by step and are already largely available to users.

Modification of the Procedure for Assessing Pavement Condition

The procedure employed for assessing pavement condition is a key system element for the technical and economic evaluation of maintenance strategies as well as for the definition of the target functions of the optimization process.

In the context of the pilot-application of the Austrian PMS on two motorways (total length approx. 240 km) the procedure for assessing pavement condition was first tested in practice and evaluated. In spring 2000 the results were put under critical assessments by the involved road-administrations and the ISTU. This evaluation required a repeated subsequent modification and calibration of the procedure. Apart from sensitivity analyses, experiences gained from the first field application were used in modifying the procedure (combination and weighting rules), which will be shortly described as follows.

Since, as a rule, each performance characteristic covered represents only one aspect or one property of the road pavement, the individual dimensional values obtained for the various characteristics first have to be standardized as dimensionless indexes, then aggregated into sub-indexes by applying weighting and combination rules, and finally aggregated into an overall index (Weninger-Vycudil 2003a).
For transforming dimensional values, standardization functions are employed which enable an assessment of the damage or defect as a function of the importance of the road. The dimensionless values thus obtained are aggregated by applying weighting and combination rules to yield a comfort and safety index (CSI) expressing riding safety and riding comfort and into a pavement and distress index (PDI) standing for the structural status of the pavement. Which characteristic is used for which sub-index depends on the property that a characteristic describes. Basically, a characteristic may influence both CSI and PDI. The total condition index (TCI) resulting from the sub-indexes can be used, on the one hand, for calculating the benefit of a maintenance strategy (traffic-weighted technical effect of a maintenance activity performed under a strategy) as well as for defining the target function as part of the optimization process (e.g. optimization of the overall index within the framework of budgetary constraints). The chart below (Figure 3) shows a schematic representation of the procedure used for assessing the condition of flexible pavements.

The combination of the procedure with deterministic pavement condition prediction models relating to individual characteristics permits the use of the procedure at any time during the period being analyzed and, beyond that, the prediction of sub-indexes and the overall index.

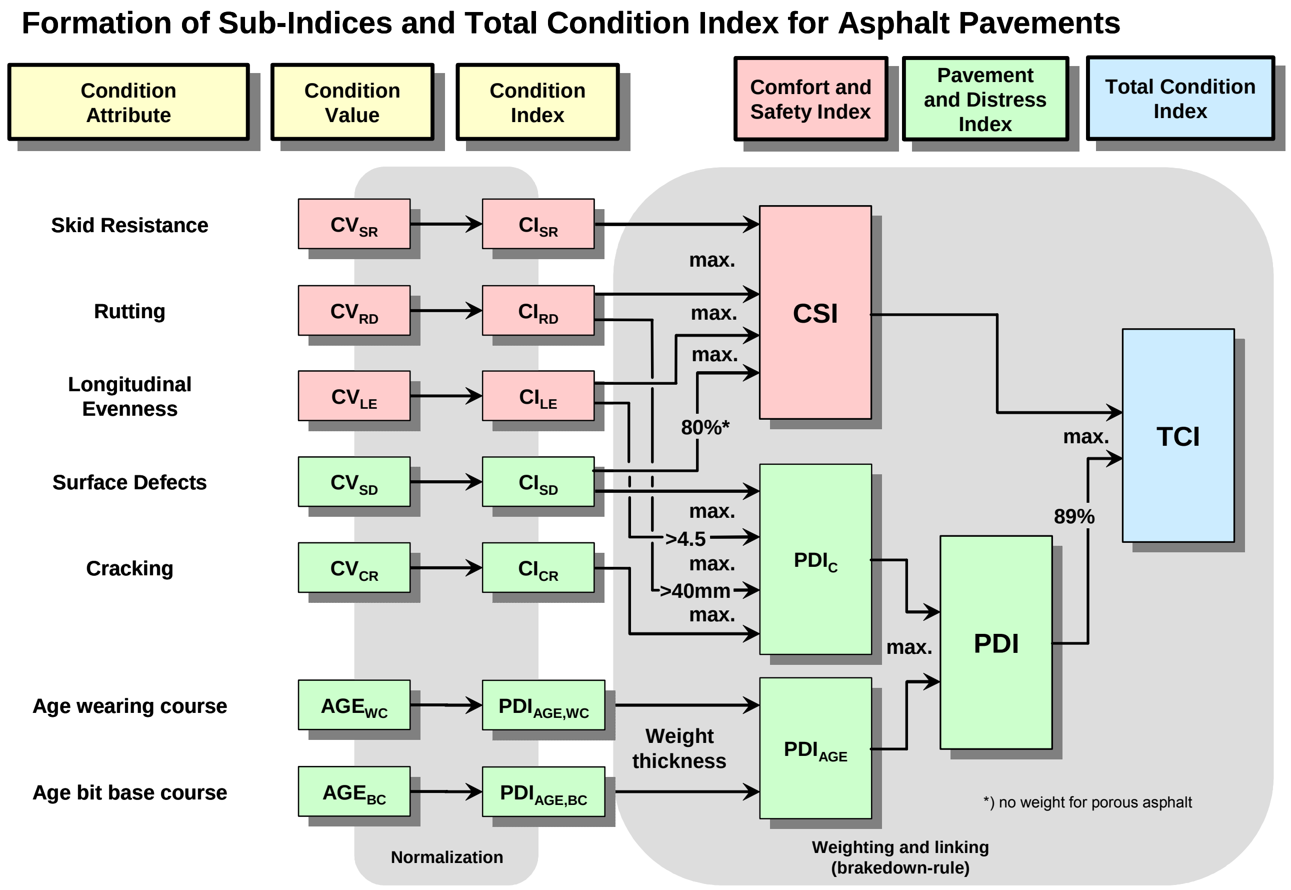

Figure 3 Formation of sub-indices and total condition index for asphalt pavements according to (Weninger-Vycudil et al 2003d)

Development of an Algorithm to Create Road Segments Featuring Homogeneous Pavement Conditions

When pavement condition data are captured for short road sections (a maximum length of 100m), it is recommended to combine sections with almost identical values into longer homogeneous segments, to which representative values can then be assigned. This reduces the number of data to be stored in the database. Also, these homogeneous segments may be used as a basis for specifying sections for maintenance or analytical purposes.

In Austria, pavement performance characteristics such as rutting, skid resistance and longitudinal evenness are currently determined in pavement condition surveys in which measurements are performed at intervals of 50 meters. For the reasons named above, combining individual data into values for longer segments with homogeneous pavement conditions would be an advantage.

For combining individual sections and for determining the boundaries of homogeneous segments, a variety of methods may be used. In most cases, such methods are based on trend analysis methods, which simplify the data series (e.g. sliding average) to identify a change in the development (trend). Most of the methods based on trend analysis define a segment boundary as a change in the orientation of the trend line, which in the case of widely diverging measurements may result in a large number of segment boundaries, and in the case of a slow continuous rise in an insufficient number of segment boundaries. Statistical procedures, on the other hand, look at the series of measurements rather than the trend line. Segment boundaries are introduced when the pattern of the measurements changes (e.g. a section with substantial dispersion of data, a section with constant values ….). The drawback of statistical procedures is attributable to the fact that they require substantial computational effort and, therefore, can take only a certain quantity of measurements into account at a time.

Despite these limitations, a statistical method for creating segments characterized by homogeneous pavement conditions has been implemented in the Austrian PMS. The software solution used for this purpose is, however, contained in a separate module outside the rest of the system, which communicates with the database by means of export and import functions.

For identifying segment boundaries, a statistical procedure was chosen that assigns to each point in the series of measurements a probability of its being a limit point (change point of the model) of a homogeneous segment. The procedure developed by F. Thomas, which is based on the Bayesian updating process (see Thomas 2001 and Thomas 2003), was adapted for field application in co-operation with VTI and implemented in special software named *SAMs*Road© (Statistical Analysis of Measurement Series on Roads). How high the probability has to be for a measuring point to be defined as a change point is left to the user. In network level analyses, a higher probability (e.g. 90%) will usually be used as a limit value than in evaluations at project level. In addition, the probability for each performance characteristic to be analyzed (rutting, longitudinal evenness, etc.) should be specified individually and the result of the analysis evaluated by an engineering expert.

The software developed at the ISTU can basically be applied to any performance characteristic being measured and permits an assessment of the results from an engineering perspective as well as editing of the results (introducing or removing segment boundaries).

Improvement of Existing and the Development of New Pavement Condition Prediction Models

In 1999, the ASFINAG commissioned a pavement survey covering some 1,900 km (i.e. some 3,800 km of carriageway) of the Austrian motorway and expressway network. This survey comprised the automated assessment of pavement characteristics – rutting, longitudinal evenness, skid resistance, and texture - by means of a high-performance measuring system (RoadSTAR). Measurements were taken every 50 meters and stored in digital format. Thus a total of approx. 75,000 data records were obtained for each performance characteristic. On behalf of ASFINAG, the ISTU processed the data, combined them into longer homogeneous segments and implemented them in the VIABASE_AUSTRIA road data base.

In 2000, a visual assessment was carried out, which covered Austria's entire major road network (motorways, expressways and national roads; total length about 12,000 km) to record structural performance characteristics such as surface defects and cracking. Like the data obtained from the 1999 pavement survey, the results were implemented in the VIABASE_AUSTRIA road data base.

Under a research project sponsored by ASFINAG and the BMVIT (Federation Ministry of Transport, Innovation and Technology), new and enhanced performance functions (pavement condition prediction functions) were developed, which are to provide a sound basis for improving the prediction of pavement conditions in the Austrian PMS (VIAPMS_AUSTRIA). This work was based on findings obtained under the research project "Statistical Methods for the Evaluation of Pavement Condition Data" and the application of Bayesian statistical methods (Molzer et al 2000).

Beside the detailed regression models evaluated for various types of pavements, simplified performance models were derived for the ongoing development of VIAPMS_AUSTRIA. The regressors used include the Age, the cumulated traffic load cumESALs, the design index DI, and the frost index FI.

Simple linear models were used for the performance characteristics rutting RD, longitudinal evenness LE, and surface defects SD. A logarithmic model was found appropriate for the pavement characteristic cracking CR (see Figure 2). For the performance characteristic skid resistance it has not been possible to develop a performance model (Molzer et al 2002a und Molzer et al 2002b).

$$RD = a_{RD} \cdot Age + b_{RD} \cdot cumESALs$$

$$LE = 1 + a_{LE} \cdot Age + b_{LE} \cdot cumESALs$$

$$SD = -12.672 + a_{SD} \cdot Age + 0.66 \cdot FI$$

$$CR = \exp\left(1 - 4.60517 + a_{CR} \cdot Age + \ln\left(Age + 0.01\right) - 0.5 \cdot \ln\left(DI + 0.01\right)\right)$$

where	Age	Age of layer (wearing course)
	cumESALs	Cumulative ESALs
	FI......................	Frost Index [Kh]
	DI	Design Index (DI≤0.5…underdesigned pavement; 0.5<DI<2…properly designed pavement; DI≥2…overdesigned pavement)
	a_i, b_i..................	Model-parameters of characteristic i

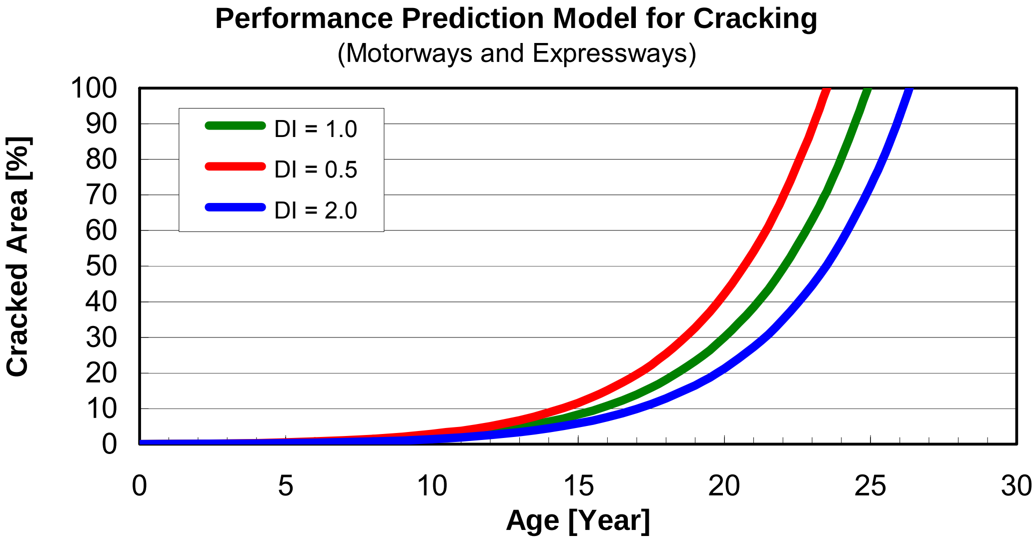

Figure 2 Performance prediction model for cracking on motorways and expressways according to (Molzer et al 2002a)

From experience gained through the statistical evaluation of pavement condition data (Molzer et al 2000, Molzer et al 1997), the following conclusions can be drawn:

- A pavement survey based on measurements is by all means preferable to a visual inspection.
- An interpretation of the data by a professional engineer is indispensable.
- Additional analyses of the types performed (Bayesian regression models) currently cannot lead to any further improvements of the models due to the multitude of parameters that cannot be assessed and the resulting dispersion of data.
- Given current data availability, improvements in performance models through the application of Bayesian statistics are currently expected to be achievable only through the inclusion of expert opinions (surveys).
- With regard to PMS at network level it may be concluded that simple linear or logarithmic functions can be applied with sufficient accuracy.
- For network level PMS, periodic pavement condition surveys are indispensable as a basis for calibrating the models section by section and thus to reduce the respective forecasting period.
- Because of the large number of parameters that cannot be assessed (material properties, quality of layer placement, quality of subgrade, …), it is currently not possible to develop generalized performance models not requiring pavement condition surveys for PMS purposes.

Section-based calibration of deterministic performance functions

The pavement performance prediction models developed in Austria under dedicated research projects (Molzer et al 2000, Molzer et al 2002a und Molzer et al 2002b) are general functions, which were designed using the entirety of pavement performance information available (measurements and visual assessment), traffic data, pavement data and climate data and are representative of Austria. For the purposes of section-based analysis and the assessment of pavement performance it must be assumed, however, that the general model will most likely not reflect the conditions found on specific sections. In order to be able to make forecasts nonetheless, the individual models have to be calibrated to the conditions prevailing on specific sections. According to (Weninger-Vycudil 2003a), calibration is carried out in a three-stage process:

- Stage 1: Selection of a suitable performance function taking into account regional requirements and boundary conditions

- Stage 2: Application of section-based inputs (explanatory variables) to the model (e.g. age, total number of load cycles, frost index, etc.)

- Stage 3: Adaptation of the model to reflect the outcome of the pavement surveys performed on the section concerned

For Stage 3 of the section-based calibration, two different calibration methods are available according to (Weninger-Vycudil 2003a), the use of which depends on the volume of pavement performance information or measurements in hand:

- Method 1: calibration based on a series of consecutive measurements (serial measurements method)
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- Method 2: calibration based on a single measuring point (measuring point method)

Beside the need for a series of measurements (with the minimum being two values measured at different times), care must be taken with Method 1 to identify any discontinuities within a series of measurements that may be attributable to maintenance measures taken between measurements, changes in the recording or measurement procedure, etc.. Taking into account pre-existing information (explanatory variables, regressor variables), a regression can be performed to change the model parameters (factors) to obtain a section-based function (Weninger-Vycudil et al 2003c).
As only two measuring exercises covering all motorways and expressways have been carried out to date and the data are comparable only subject to some reservations, calibration can currently be performed only by using Method 2 based on one measuring point.
With the measuring point method, only one single value for the performance characteristic concerned has to be available on the section being analysed. The performance function can be adjusted by

- changing the function through application of a “calibration factor” or by

- shifting the performance function using a “calibration vector”

while observing certain boundary conditions. With this method, the last value in a series of measurements is necessarily an element of the section-based performance function. Compared with calibration based on a series of measurements (Method 1), the measuring point method is, however, significantly more sensitive to measuring or recording inaccuracies.
The performance function of a performance characteristic *i* on section *j* calibrated by applying a calibration factor is defined by the following function (Weninger-Vycudil 2003a):

$$Y_{i,j}^{*} = K_{i,j} \cdot Y_{i,j} = \frac{CI_{i,j}^{*}}{Y_{i,j}\left(t^{*}\right)} \cdot Y_{i,j}$$

where $Y_{i,j}^{*}$ .... Calibrated performance function on section j of characteristic i
$Y_{i,j}$ .... Non-calibrated performance function on section j of characteristic i
$K_{i,j}$ .... Calibration factor on section j of characteristic i
$CI_{i,j}^{*}$ .... condition value of characteristic i on section j at last inspection time t^{*}
$Y_{i,j}(t^{*})$ .... Function value of performance function of characteristic i at time t^{*}

This simple form of calibration leads to a change in the slope of the function while the boundary conditions at the origin of the function remain unchanged. The same method can basically be applied to functions with exponential model parameters, but the selection of the model parameter to be calibrated and the calculation of the factor are much more complex (depending on the function). In the Austrian PMS, the performance characteristics “cracking” and “rutting” are calibrated through application of a factor.

Application of a calibration vector shifts the deterministic performance function either vertically or horizontally to the desired starting point. An important prerequisite for the application of this method is observation of the boundary conditions at the beginning of the function (= point of last rehabilitation or construction of pavement) provided that pavement condition data are available at that time. If the performance function of a performance characteristic *i* with *n* real variables is represented as a column vector of the dimension *n* and if at least one explanatory variable (regressor) is a time-dependent parameter (e.g. Age), the section-based calibrated performance function is calculated as follows (Weninger-Vycudil, 2003a):

$$\vec{Y}^{*}_{i,j} = \vec{Y}_{i,j} + \vec{K}_{CI,j} = \begin{pmatrix} X_{1,j}(t) \\ X_{2,j}(t) \\ X_{3,j}(t) \\ \vdots \\ Y_{i,j}(X_{1,j} \dots X_{n,j}) \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ \vdots \\ CI^{*}_{i,j} - Y_{i,j}(t^{*}) \end{pmatrix} = \begin{pmatrix} X_{1,j}(t) \\ X_{2,j}(t) \\ X_{3,j}(t) \\ \vdots \\ Y_{i,j} + \left(CI^{*}_{i,j} - Y_{i,j}(t^{*})\right) \end{pmatrix}$$

where $Y_{i,j}^{*}$ .... Calibrated performance function on section j of characteristic i
$Y_{i,j}$ .... Non-calibrated performance function on section j of characteristic i
$K_{CI,j}$ .... Calibration vector on section j of characteristic i
$X_{i,j}(t)$ .... time-dependent variable on section j of characteristic i
$CI_{i,j}^{*}$ .... condition value of characteristic i on section j at last inspection time t^{*}
$Y_{i,j}(t^{*})$ .... Function value of performance function of characteristic i at time t^{*}

In the Austrian PMS, the performance characteristics “surface defects”, “longitudinal evenness” and “skid resistance” are calibrated through application of a vector.

Austrian Structural Number for Bituminous Pavements

For assessing the load-bearing capacity of bituminous pavements and for calculating the required thickness (and thus the cost) of overlays a procedure has been developed that is based on the “structural number” defined in the AASHTO Guide (AASHTO 1986). To permit its widest possible application to the road network to be analyzed, the “structural number” was adapted to the characteristics of materials commonly used in Austria (material coefficients) as well as expanded to apply not only to “new” pavements (with all bound pavement layers being placed at the same time) but also to pavement structures that have already been rehabilitated once or twice. The result of these additions is the “Austrian structural number”. At the time of the most recent rehabilitation or reconstruction of the pavement this number is calculated as follows (Weninger-Vycudil 2003a):

$$ASN_{t=0,j} = \sum_{i=1}^{n} \left(D_{i,j} \cdot a_i \cdot r_{A,i,j} \right) + ASN_{Sg}$$

where $ASN_{t=0,j}$ .... Austrian Structural Number on section j at time t=0
$D_{i,j}$ .... Thickness of layer i on section j
a_i .... Material-coefficient of layer i
$r_{A,i,j}$ .... Reduction factor “Age” of layer i on section j
ASN_{Sg} .... Austrian Structural Number for the subgrade

Beside the thickness and the material coefficients for the individual pavement courses an additional factor was introduced, which represents the structure’s past history. The relationship between the reducing factor “age” and the age of the pavement course at the time of the last rehabilitation derived from the empirical distribution of the actual service lives of bound layers is expressed by the following equation:

$$r_{A,i,j} = -0.0315 \cdot Age_{i,j,t=0} + 1.234 \quad \text{for} \left[0.3 \le r_{A,i,j} \le 1 \right]$$

where $Age_{i,j,t=0}$ .... Age of bound layer i at time t=0

Any decrease in load-bearing capacity is attributed exclusively to the bound layers. The age of the unbound layers at the time of the last rehabilitation is not taken into account.
The Austrian structural number, which is defined as a time-dependent variable, can be determined at any time during the period being analyzed and takes into account both the initial situation and the current structural condition of a pavement by including PDI (see procedure for assessing the pavement condition) in the function.

$$\begin{aligned} ASN_{t,j} &= ASN_{t=0,j} - D_{Asphalt,j} \cdot a_{Asphalt} \cdot r_{A,MV,Asphalt,j} + D_{Asphalt,j} \cdot a_{Asphalt} \cdot \min\left(r_{A,MV,Asphalt,j}, r_{PDI,j,t}\right) \\ &= ASN_{unb.layers,j} + D_{Asphalt,j} \cdot a_{Asphalt} \cdot \min\left(r_{A,MV,Asphalt,j}, r_{PDI,j,t}\right) \end{aligned}$$

with:

$$r_{A,MV,Asphalt,j} = \frac{\sum_{i=1}^{n} \left(D_{i,bit,j} \cdot r_{A,i,j} \right)}{D_{Asphalt,j}}$$

$$r_{PDI,j,t} = -0.175 \cdot PDI_{j,t,Asphalt} + 1.175 \quad \text{for } \left[0.3 \le r_{PDI,j,t} \le 1 \right]$$

where $ASN_{t,j}$ .... Austrian Structural Number on section j at time t
$ASN_{unb.layers,j}$ ..... Part of the Austrian Structural Number for unbound layers on section j
$D_{Asphalt,j}$ .... Total thickness of bituminous bound layers on section j
$a_{Asphalt}$ .... Material-coefficient of asphalt
$r_{A,MV,Asphalt,j}$ .... Mean value of reduction factor “Age” of bituminous bound layers on section j
$r_{PDI,j,t}$ .... Reduction factor PDI on section j at time t
$D_{i,bit,j}$ .... Thickness of bituminous bound layer i
$SI_{j,t,Asphalt}$ .... Structural Index for asphalt pavements on section j at time t

The relationship between the permissible standard load applications and the Austrian structural number has been established through the standardized structures specified in the Austrian pavement design guideline (RVS 3.63 1998) and can be seen from the following equation:

$$ESALs_{allow,t,j} = 4.6996 \cdot \exp\left(0.8774 \cdot ASN_{t,j} \right) \quad \text{for } \left[0.1 \le ESALs_{allow,t,j} \le 50 \right]$$

where $ESALs_{allow,t,j}$ ...... Allowable ESALs (10 tons) on section j at time t

The required thickness of bituminous overlays is obtained as the difference between the pavement’s existing ASN and the required ASN of the bituminous pavement courses in a new structure (comparative method).
If the required thickness of an overlay is known, one can also calculate the costs of the maintenance work and thus perform an economic assessment as part of a benefit-cost analysis. The thickness calculated may, in addition, be used as a basis for further analyses at project level (core analyses, measurements of load-bearing capacity, etc.).

User Cost Module

The application of cost-benefit analysis in the Austrian pavement management system requires a definition of the benefits realized by carrying out a maintenance activity and of the costs incurred for this purpose. While the costs can be determined with relative ease, an analysis of the benefits requires not only the knowledge of all the effects of maintenance activities but also the knowledge of how the impact of these external effects on the social environment can be quantified for subsequent comparison with the costs of the measures taken. The “benefit” component basically comprises the entirety of effects of a maintenance activity on society and the natural environment. In conducting a cost-benefit analysis, the external effects are assigned monetary values by using appropriate procedures. This yields the so-called “social costs”, which have to be considered in the cost-benefit analysis to ensure the validity of the macroeconomic analysis of maintenance strategies. Cost-benefit analysis is the economic instrument that is used to assess potential variants of maintenance strategies. The aim is to identify the most economical variant and to rank strategies by their economic implications in order to be able to finally take a decision in favor of a particular option. The term “maintenance strategy” is used to refer to one or several pavement maintenance measures during the period being analyzed.

The Austrian Pavement Management System VIAPMS_AUSTRIA currently determines benefit as a function of the condition of a specific road segment during the period being analyzed and the nature and/or effect of the maintenance strategy. The development of the aggregate index or the sub-indexes (net asset value or serviceability index) is used as a representative indicator of pavement condition for all appropriate maintenance strategies and compared with the effect of a “no intervention” strategy. The area between these two performance functions is multiplied by the annual average daily traffic carried by this road section and the resulting product used as a measure for the benefit produced by a maintenance strategy. The road users’ interests are taken into account by according more weight to serviceability than to net asset value in synthesizing net asset value and serviceability into an overall index. With this procedure, the measure for the benefit is not a variable that can be expressed or valued in monetary units but a ratio that reflects the effectiveness of maintenance strategies over the period being analyzed relative to a “no intervention” strategy.

This procedure is a pragmatic engineering approach to the assessment of maintenance strategies and was therefore used for the analysis conducted under VIAPMS_AUSTRIA. However, a number of effects produced by the implementation of maintenance activities were not taken into account and led to higher costs for the company. These additional cost components are, however, not necessarily proportional to the level of the agency costs. Development work on the Austrian PMS is being continued in order to consider these effects on the economy as well when determining the most economical pavement maintenance strategy. For this purpose, existing calculation models for the macro-economic analysis of maintenance measures are analyzed in a first step. In a second step, an analytical module will be modeled that is adapted to conditions in Austria in terms of data availability and implementability in the existing PMS. This module will be implemented in VIAPMS_AUSTRIA and, as part of the analysis, will supply a parameter assessing the overall economic impact of a maintenance strategy for subsequent comparison with the costs (agency costs). The following parameters have been evaluated to determine the external effects,:

- Pavement condition
  In general, a maintenance activity improves pavement condition and thus benefits the road users (e.g. fuel savings), ultimately lowering their costs. In this case, a comparison has to be performed with a reference situation (e.g. comparison of pavement condition before and after the work done).

- Effect of road works
  As a maintenance activity is being carried out, traffic obstruction usually produces negative effects, which implies additional costs referred to as additional road user costs. In this context, travel speed is a major consideration, any change of which causes effects such as longer journey times and thus additional costs.

- Change in traffic routing or road geometry
  The new construction of a traffic route or the construction of a bypass, like a change in road geometry (e.g. addition or removal of a lane), may also have a significant impact on road user costs.

The said factors affect mainly the following parameters:

- the road users' journey times
- fuel consumption
- accidents and the
- environment

The changes in the parameters named are assigned monetary values and referred to as road user costs (even though cash flows are not necessarily involved).
A large number of European and international studies, guidelines and pavement management systems provide models for calculating road user costs. These models were developed in different national settings, on the basis of widely differing data, and therefore cannot be applied in other countries in the same manner. In view of the abundance of models already available, a preliminary selection was made with the main criterion being their adaptability to conditions in Austria. The criteria used included:

- analysis at network level
- applicability of the module to the high-level road network
- availability of equivalent data in Austria
- general conditions adjusted to a European environment (e.g. climatic conditions, pavement design, etc.)
- ease of integration into the Austrian pavement management system
- ease of programming in dTIMS_CT analytical software
- additional analytical module in existing VIAPMS_AUSTRIA PMS, which may be “added” as needed and provides an additional assessment parameter for road maintenance strategies

With these general conditions in mind, the following mathematical models or model components were studied (selection):

- Austrian guideline “Economic evaluation of road pavement designs” (RVS 2.21 2001)
- German guideline “Recommendations for the economic evaluation of roads (EWS 1997)
- PAV-ECO project “Economic Evaluation of Pavement Maintenance” (PAV-ECO 1999)
- FORMAT project “Fully Optimized Road Maintenance“ (FORMAT 2003)”

The development of the novel mathematical model for VIAPMS_AUSTRIA is ultimately based on the findings of a variety of studies, guidelines or other pavement management systems. In some cases, only parts or individual model components were used for determining the relevant parameters.

At the moment the ISTU works on the development of this algorithm and parallel of the computer-assisted instrument, which finally includes all cognitions from the analyzed studies. This mathematical model is going to be implemented in the last version of the dTIMS© - software, called dTIMS_CT© (Deighton Associates Limited, Total Infrastructure Management Software, Concurrent Transformation).

The finished analysis module permits subsequently the application to an existing road network and furthermore, an analysis of a wide range of scenarios. The effects resulting from a change in input parameters (sensitivity analyses) can be highlighted as well as the impact on results (ranking of variants) when one single factor or a combination of several parameters are taken into account.

CONCLUSIONS AND OUTLOOK

9The results of research work and research projects described here represent a sound basis for the continuing development of the Austrian PMS. Like any other management system, the PMS is also subject to continuing developments affecting not only the software employed but also the models and algorithms used in the system. In order to ensure the system’s functionality for field use in the coming years, its modules have to be updated continuously or periodically, which will require continuing research work in this field. This will include, most importantly, the development of new components and modules to account for user costs, the improvement of pavement condition prediction models and the aggregation of the results of pavement management into an overall maintenance management system covering other elements of the road infrastructure as well (bridges, tunnels, walls, etc.).

Over the past years, the Austrian road administration bodies have come to realize that advanced maintenance management systems are the only instruments available that underline the need for an allocation of budget resources for the structural maintenance of roads in an objective manner and clearly pinpoint the consequences of any failure to take the necessary action. It is, however, primarily up to those responsible for road maintenance to use this system as efficiently as possible so that the results derived from it can be used effectively in formulating the necessary arguments and, ultimately, in the decision-making process.

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