InteMat4PMS

Integration of material-science based performance models into life-cycle-analysis processed in the frame of pavement management systems

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Deliverable D3: Manual for developing PMS based on physical performance functions

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Deliverable 3: Manual for developing PMS based on physical performance functions

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1 Introduction

1.1 Objective of the manual

The "Manual for developing PMS based on physical performance functions" is a basis for the practical implementation of pre-selected performance functions into a Pavement Management System (PMS). It includes a comprehensive description of the different steps for the selection of models, the selection of an adequate PMS solution and finally for the incorporation of laboratory calibrated empirical performance functions into PMS.

Following the tasks of work-package 4, the structure of the manual is subdivided into a theoretical part and into a part, which explains the practical implementation in form of an example. The example is based on the selection of physical performance functions described in Deliverable 2.

These steps described in this manual can be seen as a general framework for the implementation of any empirical or physical performance function into a computer assisted PMS. Thus, the described processes can be understood as a general approach, which is adaptable to similar projects and problems.

1.2 Explanation of terms

For a comprehensible understanding of the content of this manual a short explanation of different terms is given. The definition is in full coincidence with the terms used in the previous deliverables.

Physical performance function:
A physical performance function is a (mathematical) model for the description of the stress / time-dependent behavior of physical properties of road pavements or pavement materials.

Empirical performance function (EPF):
Any performance function based on empirical information (e.g. from condition measurements, mechanistic analysis based on laboratory testing results, etc.) is called empirical performance function.

Life-cycle-assessment (LCA) and Life-cycle-cost-analysis (LCCA)
In general, LCA/LCCA is a method to assess the behavior of a road pavement or pavement material over a certain time period including the loadings and the effects of maintenance treatments. If costs are considered, LCA leads to LCCA.

Benefit/cost-analysis:
Benefit/cost-analysis is used to compare the (ownership) costs with the benefit of a maintenance treatment over a certain time period. The benefit can be defined as the positive effects of a maintenance treatment on the condition and/or the different stakeholders (users, neighbors, environment, etc.). The benefit can be expressed either by a monetary value or as a technical function (e.g. "Area Under the Curve", see Figure 4).

2 Background for developing PMS based on physical performance functions

2.1 General framework for PMS development

The approach followed up for PMS development is based on single steps, which are categorized on the one hand by a selection process and on the other hand by the implementation process of EPF including calibration procedures for the incorporation of laboratory testing results into a holistic solution. The following framework gives an overview of these steps. In the following chapters a detailed description of these sub-processes and of all requirements for the selections is given.

Figure 1 shows the general framework for the PMS development using physical performance functions.

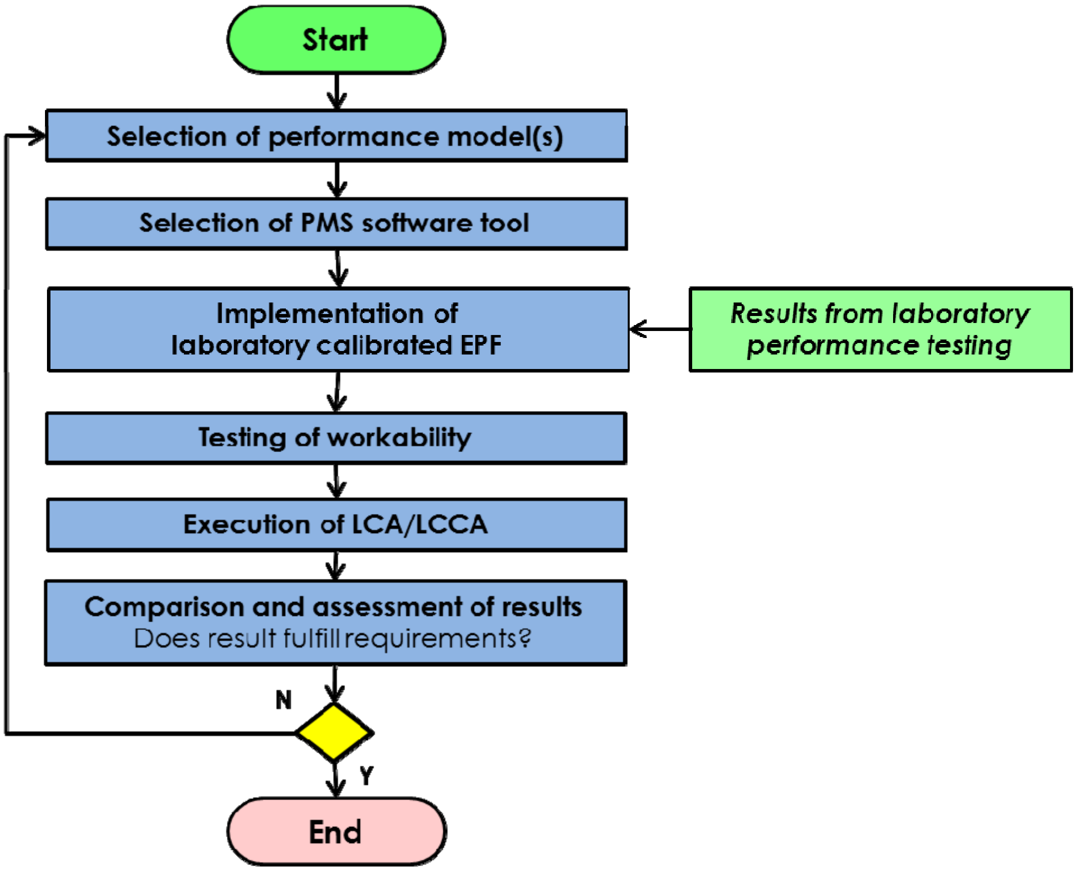

Figure 1: General framework for the PMS development

2.2 Selection of performance model(s)

Independently from the type of deterioration and the pavement properties to be assessed, the performance models have to fulfill different requirements before the implementation process can be started. The following list is a general overview of these requirements, which have to be fulfilled:

- The local data and information can be used as input parameter in the selected model

- The model fulfills all local requirements.
- The model represents the technical state-of-the-art and is in accordance with the experiences of the local engineers.
- The model describes the physical pavement performance properties to be assessed sufficiently.
- The model can be linked to specific laboratory tests and uses a similar loading assumption (e.g. load cycles).
- The model can be described by mathematical (deterministic or probabilistic) functions.

2.3 Selection of PMS software tool

The improvement of the PMS-efficiency is of major concern for a modern and future oriented road administration.

A holistic PMS-solution can be realized by either a fully flexible commercial software tool or by a project specific, tailor-made software solution. The following general requirements can be considered for selection and decision respectively. The system should be suitable

- to store all model specific data and information of the road sections,
- to define a model specific data base structure,
- to integrate the mathematical procedures and to prepare the data for the analysis,
- to implement the pre-selected performance prediction models and functions,
- The system should be able to implement a mathematical procedure for the calibration of pre-selected performance prediction models and functions.
- to define and execute LCA or LCCA on all road sections,
- to define user-specific optimization procedures by using benefit/cost analysis, and
- to export all results from the analysis for further processing.

2.4 Implementation of laboratory calibrated EPF

2.4.1 Overview of approach

The implementation of a LCA/LCCA application is based on several steps, which enable a repeatable and adjustable processing under the given requirements. ***InteMat4PMS*** focuses on the implementation of mechanical analysis based on laboratory testing and the respective calibration of the underlying EPF. The different, pre-selected EPF have to be incorporated into a fully working LCA/LCCA approach. This approach shall be capable to compare and to assess different maintenance treatment strategies. Based on the experiences of the project team, the given requirements and the objectives of ***InteMat4PMS***, the following process (see Figure 2) is proposed for the implementation of laboratory calibrated EPF.

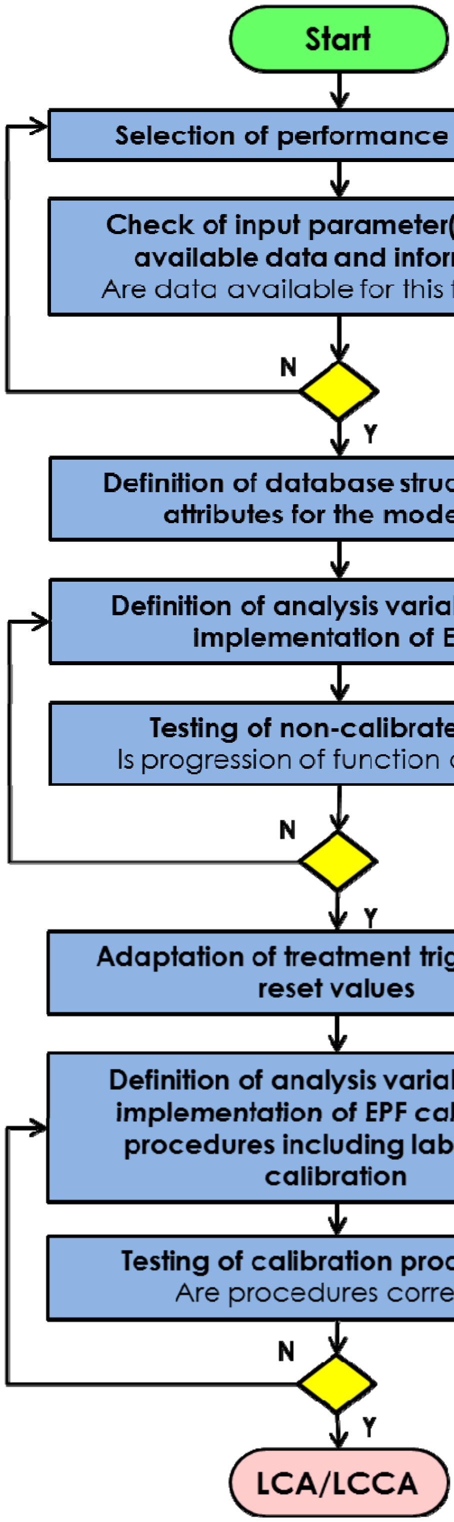

Figure 2: Outline for the implementation procedure

In the following chapters a comprehensive description of the implementation steps shown in Figure 2 is given. These steps form the general framework for the implementation of any EPF into a computer assisted PMS including a calibration procedure for the incorporation of laboratory testing results. Furthermore, this approach exemplarily shows the outline of EPF-implementation which can be adapted and extended to other performance indicators as well as to other economic assessment methods (e.g. asset value development, minimize cost optimization, etc.).

2.4.2 Steps of decision process

(a) Selection of performance function

The first step is the selection of the appropriate (physical) performance function, which describes mathematically the behavior of the pavement material or layer over time (or load repetitions). A performance prediction model uses one or more functions with different input parameters for different pavements and materials. This means, that the selection of an adequate function has to be in accordance at least with:

- The pavement construction (type of layers, sequence of layers)
- Pavement material
- Physical characteristics to be described or assessed
- Climatic conditions and other local preconditions

(b) Check of required input parameter(s) versus available data and information

All input parameters of the functions need to be faced with available data and information. In case of lack of data, a new function needs to be selected or the function needs to be adapted (simplified).

(c) Definition of database structure and attributes for the modeling

The database is storing of all relevant information and is therefore designed in accordance with the data, models and parameters. The data can be categorized as:

- Net specific information (road, referencing points or sections, length, etc.)
- Pavement construction information (type of layers, thicknesses, construction year, etc.)
- Cross section information (number of lanes, widths, etc.)
- Traffic information ($AADT_{total}$, $AADT_{trucks}$, growing rates, etc.)
- Pavement condition information (condition attributes, year of measurement, etc.)
- EPF information (model parameters, calibration factors, etc.)
- Other relevant information (climate information, responsibilities, etc.)

(d) Definition of analysis variables and implementation of EPF

In many PMS the performance functions are defined in form of so called analysis variables. These variables enable to calculate the values of the functions by year and to store these results in a database. Because of different types of functions and other time-dependent parameters, these variables have to be defined in accordance with the parameter to be calculated. The requirements for these variables can be defined as follows:

- Definition of analysis variable type in accordance with the function to be calculated
- Storage of calculation results in a database
- Definition of inter-dependencies between different analysis variables (e.g. definition of traffic forecast within a variable and use of this variable within an EPF)

- Definition of starting point of curve based on input values (e.g. from condition measurements)

In order to guarantee high flexibility in using user-specific performance functions and to integrate specific calibration functions the PMS should allow to use flexible analysis variables as well. Thus, it is necessary to define the necessary extent of PMS-flexibilty as a selection criteria for the system.

(e) Testing of non-calibrated EPF

After the implementation of the non-calibrated functions (in form of analysis variables) the calculation process runs in a controlled mode. It is recommended, to compare the yearly values of the input parameters as well as the values of the non-calibrated EPF with test calculations executed separately from the PMS. In case of divergence the calculation process has to be revised. Furthermore, it is recommended to compare the performance functions with the results of existing applications using the pre-selected (but non-calibrated) functions.

(f) Adaptation of treatment triggers and reset values

Any PMS comprises a catalogue of possible maintenance treatments. The treatment catalogue has to be harmonized according to the new function. Thus, it is necessary to adapt or implement the following elements in the PMS:

- Adaptation of triggers:
  For modeling the maintenance treatment strategies the triggers of the maintenance treatments has to be adapted to the new EPF. A trigger can be defined as the threshold for the application of a certain maintenance treatment (e.g. reconstruction if cracking > 20%).
- Resets:
  Resets define the effect of a treatment on the EPF. The reset can be an absolute value (e.g. no cracking after reconstruction) or a relative one (e.g. reduction of 20% cracking after patching).

(g) Definition of analysis variables and implementation of EPF calibration procedures including laboratory calibration

As shown in Figure 2 the implementation of an adequate calibration procedure is an essential part for the integration of EPF and laboratory testing results into a PMS. In general, the approach consists of 2 main steps, which are based on the calibration procedures described in detail in Deliverable 2. The two steps are as follows:

1. Section based calibration of the EPF:
   The first step includes the estimation of the actual load repetitions and the starting point of the EPF. This is usually carried out in form of section based calibration (or adaptation) of the EPF by using the section-specific traffic information, the respective model-parameters and condition data from actual condition inspections or measurements. Thus, the input data for LCA/LCCA has to be prepared and the calibration has to be executed.
2. Integration of laboratory results into the EPF:
   In order to integrate the results of laboratory testing and analysis into the calibrated EPF the damage D with the corresponding load repetitions $N_{f,D}$ and the scaling factor X_f must be included in the LCA/LCCA. This is carried out by using on the one hand attributes, which are representing the damage and the number of load repetitions and

on the other hand in form of an analysis variable, which represents the necessary scaling factor (see Figure 3 and Deliverable D2).

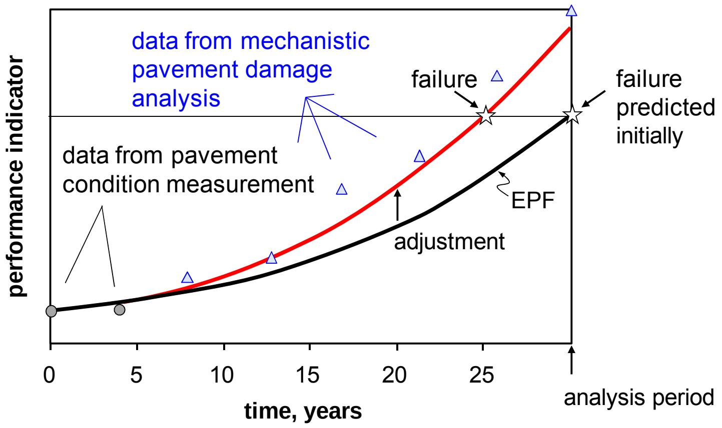

Figure 3: Principle for adjustment of empirical pavement performance function (EPF) using data obtained from mechanistic damage analysis.

(h) Testing of calibration procedures

After the implementation of the calibration procedures the calculation process needs to be controlled as well. It is recommended, to compare the yearly values of the calibrated EPF with test calculations executed out of the PMS. In case of divergence the calibration process has to be revised.

2.5 Testing of functionality

The testing of the functionality of the EPF calculation as well as of the calibration procedures is a main issue for the quality control. It is recommended to use a testing system or process, which enables to control and re-calculate the yearly values of the input parameters as well as the values of the calibrated and non-calibrated EPF on a high number of different sections and to carry out the LCA/LCCA over the whole network.

2.6 Execution of LCA/LCCA

2.6.1 Understanding of LCA/LCCA and benefit/cost-analysis

Within a modern PMS a pavement related LCA/LCCA is used to predict the future condition of a road section and to compare the effects (benefits) of different maintenance treatment strategies. The selection of an adequate maintenance solution (treatment) is usually related to technical and strategic requirements, where a target function has to be optimized. The main approach is either minimizing costs or maximizing the monetary or non-monetary benefit of all treatments over the whole network (all sections) under different (technical) constraints. Thus, performance prediction and optimization is an inseparable component of any PMS using LCA/LCCA.

Any maintenance treatment is defined as an action which (a) has a cost while (b) provides a benefit. The latter is defined in the way the treatment modifies one or more analysis variables. The combination of performance prediction and maintenance treatments enables to assess the different recommended solutions in terms of benefit/cost analysis.

There are two different types of monetary effects, which can be linked to a maintenance treatment. The first type is the ownership costs, which are costs to initially construct, to improve, to maintain and to operate the respective asset. The second group of effects is related to the users or other affected groups (stakeholders). These are the vehicle operation costs, the freight time, the accidents, etc. When determining benefits, it becomes a difference between the two sets of effects (see Deighton, 2012). The benefit to the road users usually arises from improved level of service of the road (typically reduced travel time), while the ownership costs are related to the direct monetary effect to the agency. In the benefit/cost analysis the two effects need be compared on an objective level.

While ownership costs are normally expressed in monetary terms, benefits are expressed in more abstract terms. Therefore, often an agency will assume a certain level of condition or service. It then becomes an analysis of the best and cheapest way to maintain that level (Deighton, 2012).

One measure of the benefit of a strategy is the "Area Under the Curve" (technical approach). This benefit is calculated by summing the present value of the difference between the condition index resulting from the strategy and the condition index for the do-nothing strategy for each year in the analysis period. The condition index most agencies use for calculating the area under the curve is some form of composite index which gives an overall indication of the element's condition (Deighton, 2012).

An alternative measure of the benefit is the sum of external costs during the whole life-cycle process, where the effects of the pavement condition as well as the effect caused by a maintenance treatment are expressed by monetary values (macro-economic approach). The effects can be evaluated by different indicators. The most common types are time costs, accident costs, vehicle operating costs (VOC) but also environmental costs like CO_2 equivalents or costs caused by noise. The benefit can be defined in the same way like the technical approach in form of a comparison between a maintenance treatment strategy and a do-nothing strategy calculating the savings of user costs caused by improved road condition minus the additional user costs at the construction sites for the treatments (Brozek et al., 2012). The following Figure 4 shows the different definitions of benefit.

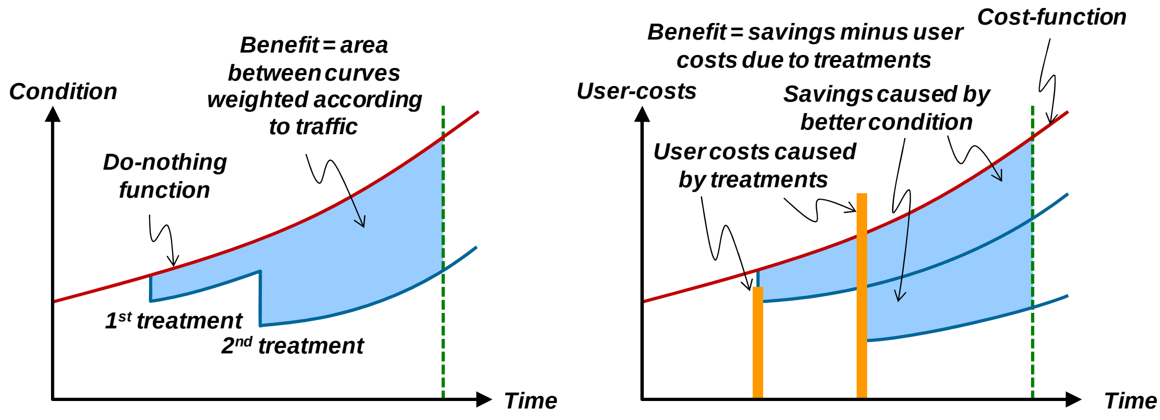

Figure 4: Definition of non-monetary and monetary benefit (Brozek et al., 2012)

Based on the calculation of the ownership costs and the benefit, a comparison between both indicators is possible and enables a selection of adequate solutions under given requirements. Figure 5 shows the efficiency graph for the selection of adequate treatment strategies in the optimization process. All maintenance treatment strategies (points in the graph) which show a low benefit/cost ratio (BC) or incremental benefit/cost ratio (IBC) have to be excluded from the optimization (e.g. S_4 or S_5). The target for the optimization is to find the best solution of the efficiency frontier under given requirements (S_1, S_2 or S_3).

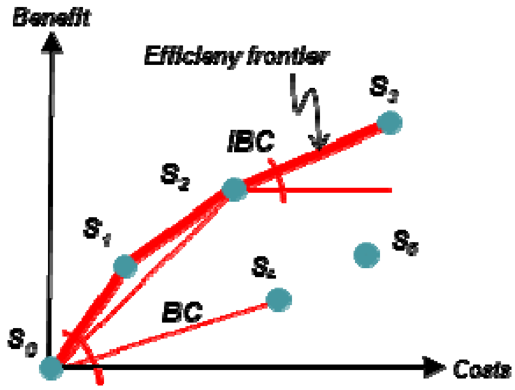

Figure 5: Benefit/Cost analysis – efficiency graph (according to Deighton, 2009)

The selected analysis scenario determines the second stage of the LCA/LCCA. Optimization normally requires two information, a target function and a resource constraint. Thus, the key components are as follows:

- Type of optimization to be used
- Parameters to be maximized or minimized in the optimization (= target function)
- Constraints

2.6.2 Requirements for the execution of LCA/LCCA

LCA/LCCA is executed in two steps. In the first step, maintenance treatment strategies are generated for each section, where the treatment catalogue of the PMS (including treatment triggers, resets, cost calculation procedures, etc.) provides the necessary basis. The second step is to select the best maintenance treatment strategy for each element. Thus, the principal requirements that need to be fulfilled for the practical execution of LCA/LCCA are as follows:

- Integration of laboratory calibrated EPF into PMS
- Provision of a treatment catalogue with treatment costs, triggers and reset values
- Implementation of a calculation procedure for modeling the costs and the benefit of a treatment strategy in the PMS
- Implementation of a calculation procedure for modeling cost/benefit analysis
- Setting of time frames for analysis (treatment application period, analysis period, etc.)
- Setting of economic factors (discount rate, etc.)
- Formulation of optimization problem in form of target function and restrictions (scenarios)
- Other settings

2.7 Comparison and assessment of results

The output of LCA/LCCA is on the one hand strongly dependent on the quality and quantity of available information and data and on the other hand on the quality of the calibrated EPF.

The comparison of calibrated with non-calibrated EPF can be based on the results of LCA/LCCA in order to assess any improvement of the integration of laboratory testing results into the PMS process on project level. The following list gives an overview of the results, which can be derived from the analysis, and their use in the following up assessment process:

- Comparison of progression (yearly values) of calibrated and non-calibrated EPF (same model)
- Comparison of progression of different calibrated or non-calibrated EPF models (e.g. HDM-4 with German model)
- Comparison of maintenance treatment strategies (type, year) by using calibrated and non-calibrated EPF (same model) or by using different calibrated or non-calibrated EPF models under given monetary of conditional constraints
- Comparison of cost, benefit and other economic indicators by using calibrated and non-calibrated EPF (same model) or by using different calibrated or non-calibrated EPF models
- Assessment of effects of different maintenance treatment strategies on the calibrated and non-calibrated EPF
- Assessment of monetary or non-monetary savings or losses by using calibrated and non-calibrated EPF

Through the assessment of the results a clear decision on the use of laboratory testing results within a PMS becomes possible. Of course, a net-wide approach will be too cost-intensive and time-consuming. Nevertheless, the experiences derived from such projects can improve existing EPF and thus improve the results and the accuracy of the prediction.

3 Example of practical implementation

3.1 Introduction

This chapter shows the practical implementation of laboratory calibrated EPF into an existing PMS software solution based on an example road network, which consists of 4 different road sections on the German federal road B35. B35 test site is located near Stuttgart/Germany, having a total length of approximately 1.6 km and approximately 9 000 vehicles per day, including approximately 20% of trucks. Based on pre-selected performance functions the necessary steps are described in detail.

3.2 Selection of software tool

3.2.1 PMS software platform

Based on the experiences of the project team, it was decided to use the commercial asset management software dTIMS CT for testing the implementation procedures and the practical application of the pre-selected EPF. This software tool fulfills all described requirements and is used by a high number of road administrations around the globe. Thus, any time-consuming programming of a tailor-made solution was omitted.

dTIMS CT is a fully flexible and user-definable PMS-solution and can be adapted to any local requirements of a project. All elements, items, processes, models, preconditions, etc. for data management and for the analysis can be defined by the user. The software solution focuses on the following main objectives:

- Integration of a flexible database structure according to the requirements and preconditions of the network to be managed
- Integration of LCCA in the asset management process for short-, medium- and long-term planning of maintenance activities by using performance prediction of key performance indicators
- Maximizing of benefits (monetary or non-monetary) under different budgetary constraints or minimizing investments under given quality requirements (e.g. condition requirements) as a part of the economic analysis (cost-benefit-analysis) of different maintenance treatment strategies for different assets
- Integration of the system into existing data management processes and provision of additional functionalities for a future oriented data management
- Extended communication between the system and other asset management tools (holistic approach), e.g. GIS-integration.
- User oriented reporting from strategic to project level decisions with regard to the different stakeholders' expectations (policy level, financing parties, users, neighbours, operators, etc.)

3.2.2 Overview of the functionality of dTIMS CT

dTIMS CT offers the possibility for users to make the PMS as "custom" as they wish to incorporate their very own database structure and analysis variables during initial system configuration or afterwards. dTIMS CT is configured during implementation to provide the data management and network analysis requirements. The flexibility of dTIMS CT leaves the door open for future modifications to the users' analysis methodology or the expansion into the management of other transportation related assets (see Deighton, 2009).

It is important to note that the open architecture of dTIMS CT makes it easy for the users to expand the PMS to other transportation related assets at any time without the added expenditure of supplementary software modules. Additional assets, models, management philosophies and analysis parameters may be configured at any time. dTIMS CT goes beyond offering the user the mere ability to store data related to other sub-assets within their PMS. A user can choose to store other asset data in dTIMS CT independent of its final use. Initially, it can be used simply for query and reporting purposes, then as an enhancement to the PMS and finally as the basis for a complete management system for that asset. As the PMS matures, Asset Managers will be able to concurrently manage assets such as roads, bridges, structures, culverts and other roadside appurtenances using a single application and even optimize budgets and/or other constraints (e.g. technical requirements) across those same assets.

The database module includes the functionalities for data storage, data exchange (concurrent transformation, queries, data export, data import, data reporting and viewing, etc.), location referencing and data preparation. Within the database module the following functionalities can be managed:

- Perspective Builder
- Data View and Form Designer
- Queries & Transformations
- Cross Section Queries
- External Data Connector
- Location Referencing Manager and Element Locations Mapper (linear strip mapping)
- Image Viewer
- Expression Builder
- dFrag Auto Sectioning

The characteristics of the road infrastructure assets can be described by tables. Each asset table, in turn, may have several related tables that describe characteristics of each asset. Each of these tables is related to the BASE table (e.g. the road network) and can have unique sectioning, according to the data they contain. In dTIMS CT these tables are called "Perspectives". Each "Perspective" that the user defines will be composed of rows (data sets) and columns (attributes). Figure 6 shows the BASE Perspective and four additional "Perspectives" as an example (Deighton, 2009).

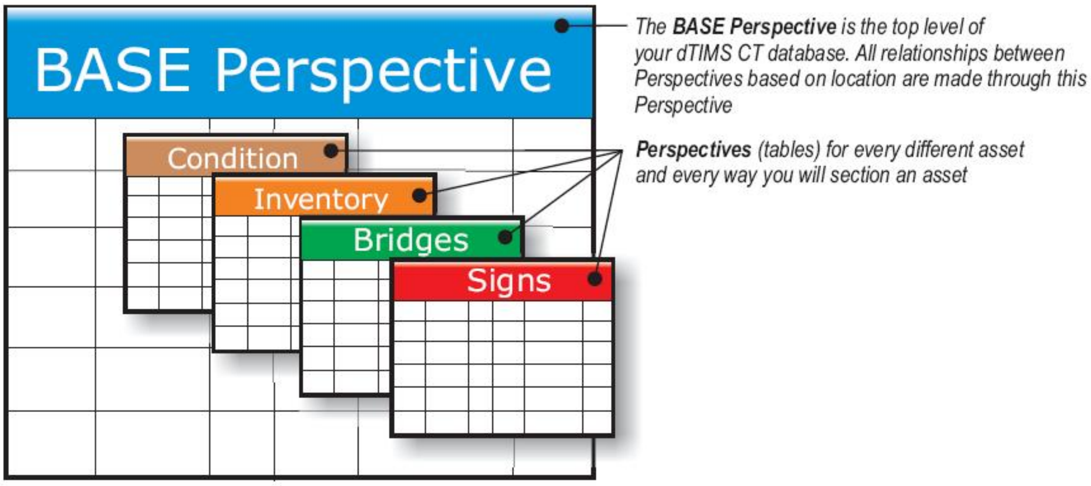

Figure 6: Conceptual view of Perspectives (Deighton, 2009)

Figure 7 shows the conceptual view of attributes and data sets/elements.

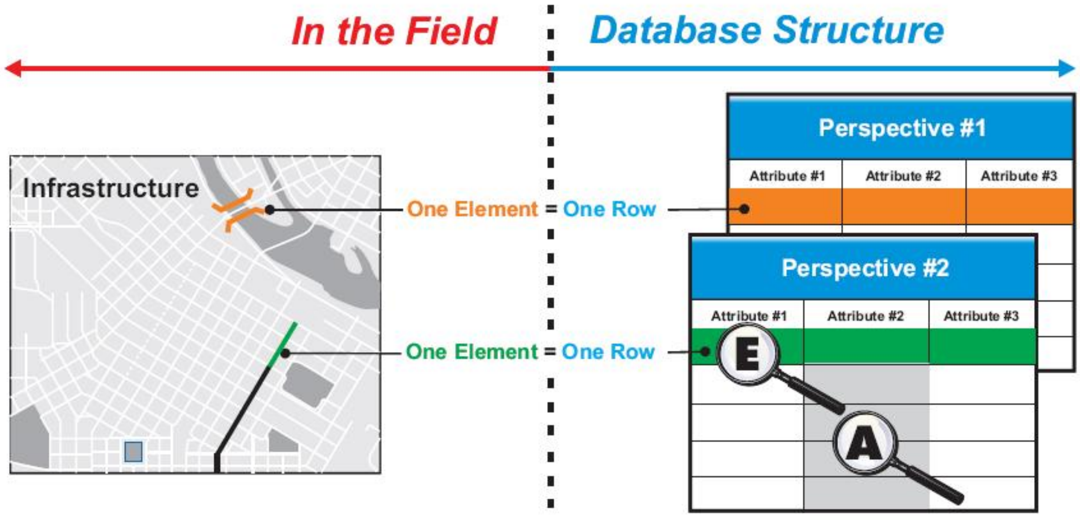

Figure 7: Conceptual view of data sets/elements and attributes (Deighton, 2009)

To fulfill the requirements for the storage of all maintenance relevant data a specific data base structure has to be implemented into dTIMS CT. The selection of perspective types (section, lane, historic, point, etc.) and attribute types (double, text, integer, etc.) should be based on the data to be implemented (type, sectioning, referencing, etc.). With regard to the available information the following perspective groups are usually implemented:

- Net Data Perspectives (road network data, functional classes, etc.)
- Location Referencing Perspectives
- Condition Data Perspectives (road condition data, road geometry data, road structural data, bridge condition data, etc.)
- Inventory Data Perspectives (pavement inventory, bridge inventory, treatment history, maintenance measures, etc.)
- Traffic Data Perspectives
- Analysis Perspectives

- Other Perspectives (temporary perspectives – staging area; committed treatments pavement, etc.)

Beside the storage of asset specific information in the database, the PMS-analysis has to be defined by using different modules. The analysis modules include the functionalities for LCA/LCCA modelling and analysis, performance prediction, economic assessment (benefit/cost-analysis, budget scenarios, etc.), review and adjust maintenance strategies, cross asset optimization, strategic and project level reporting, etc. Within the analysis modules the following functionalities are managed:

- Life Cycle Cost Analyzer
- Optimizer
- Reports and Graphics Viewer
- Life-Cycle Cost Model Debugger
- Cross Asset Analysis and Optimization
- dFrag Auto programming
- Strategic Analysis Module

To fulfill the requirements a specific LCA/LCCA setup needs to be implemented into dTIMS CT. This setup includes the following main objects:

- Analysis variables (static, dynamic, annual and compilation), which describe the time-dependent change of all relevant key performance indicators during analysis
- Maintenance treatment catalogue (types, costs, triggers, effects, etc.)
- Budget scenarios and other constraints for optimization and benefit/cost analysis
- Analysis sets (time frames, economic parameters, etc.)

For each single element (bridge, road section) a list of maintenance treatment strategies according to the LCA/LCCA setup is produced during analysis, where each single maintenance treatment strategy consists of one or "n" different maintenance treatments. dTIMS CT offers the following operational programming information (see Figure 8):

- List of input information for LCA/LCCA analysis
- List of maintenance strategies and treatments of each single element (section order) including costs, benefits, economic parameters (e.g. benefit/cost ratio) and recommendation for the selected budget (quality) scenario
- Efficiency chart (benefit/cost diagram)
- Performance prediction of all analysis variables in form of tables and charts
- Recommended construction program sorted by sections or by years (export function)

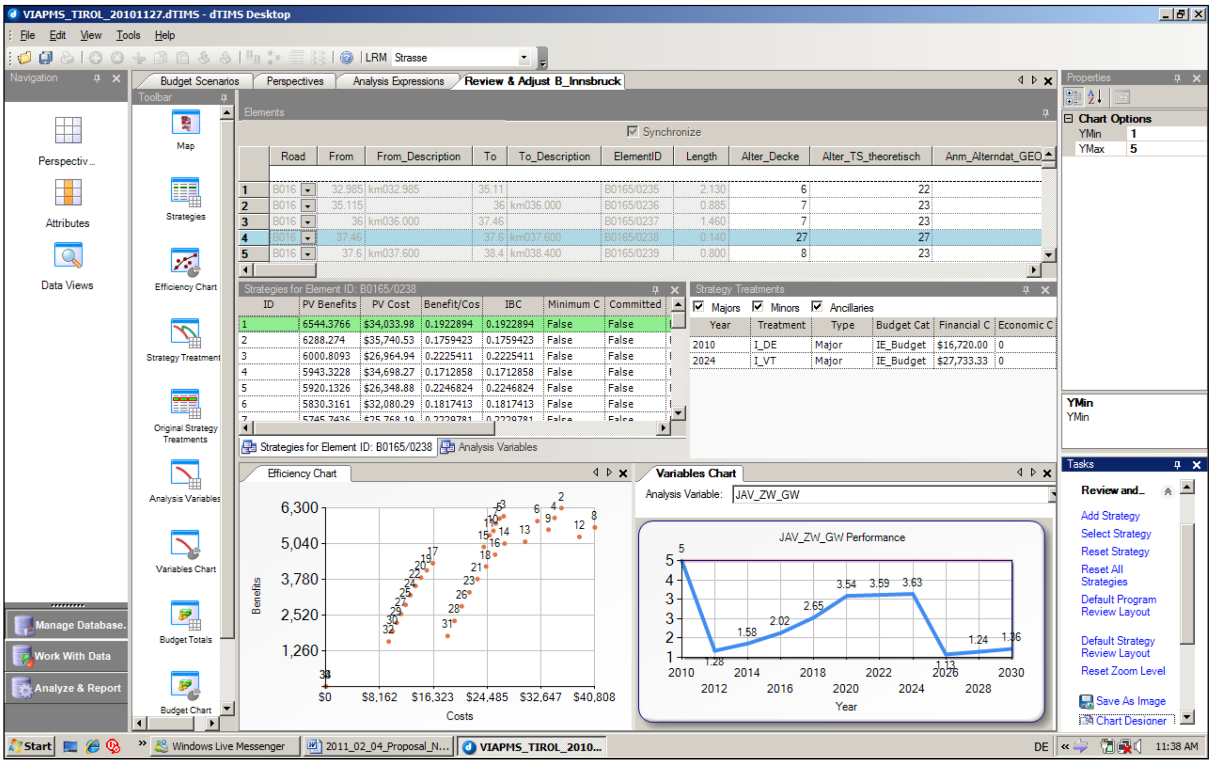

Figure 8: Operational Programming in dTIMS's Review and Adjust mode (top: list of sections, middle: strategy list with recommended green highlighted strategy and related treatments; down: efficiency chart and variable chart for key performance indicators)

The outputs for strategic planning purposes are based on the element (bridge, road section) related results of LCA/LCCA-analysis and the economic assessment within the optimization for each single budget or quality (condition) scenario. The element (bridge, road section, tunnel, etc.) related identified results will be cumulated for the whole network or for user pre-defined sub-networks (regional, functional, etc.) and include typical outputs as follows:

- Condition distribution of all key performance indicators for the whole analysis period and for all budget/quality scenarios
- Development of average condition of all key performance indicators for the whole user-defined analysis period in a comparable form for all budget/quality scenarios (example see Figure 9)

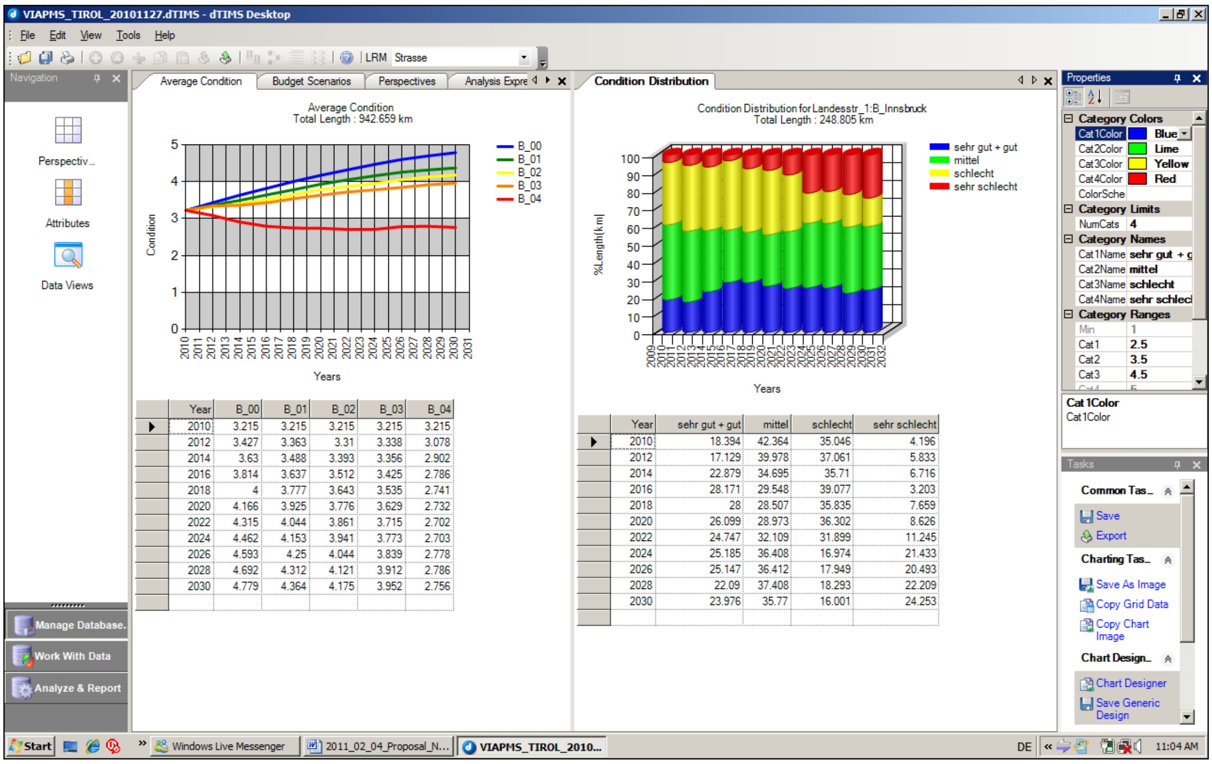

Figure 9: Strategic results within dTIMS CT (average condition development for different budget scenarios, condition distribution)

- Comparison of available and used budgets for the whole user-defined analysis period for all budget/quality scenarios
- Treatment cost and length distribution of all maintenance treatments for the whole user-defined analysis period for all budget/quality scenarios
- Development of maintenance backlog (remaining work) for the whole user-defined analysis period and for all budget/quality scenarios
- Return On Investment expressed by development of maintenance backlog and/or average network condition
- Others

All results are prepared within dTIMS CT in form of tables and completely customizable graphs and can be exported into other software products for following up preparation (MS Excel, MS Word, etc.).

In addition to the functionalities described above, the system provides the following administrative functionalities for the data management process (security, help system, external data connection, etc.).

3.3 Selection of models

Based on the selection process described in Chapter 2.2 and the specifications for physical performance assessment of pavement construction described in Deliverable D2 three empirical performance functions (EPF) for structural (fatigue) cracking were selected for testing within the general framework (see Figure 1 and Figure 2). They include:

- Austrian cracking model
- German cracking model, and
- HDM-4 cracking model for asphalt pavements.

A detailed description of these models is presented in Deliverable D2. This chapter provides assessment and comparison of the models from the point of their possible use within the general framework described in Figure 1 and Figure 2. Table 1 provides basic characteristics of the models.

Table 1: Basic characteristics of considered cracking EPF

	Model		
	Austrian	**German**	**HDM-4**
Type of indicator	Structural cracking (%)	Alligator cracking (%)	Two phase (initiation & progression) model for structural cracking (%) (wide & all cracking)
Road type	Motorways & expressways	Motorways	All
Pavement type	Asphalt pavements	New & rehabilitated pavements – 13 pavement categories	Asphalt and surface treated pavements with unbound, asphalt or stabilized base or rehabilitated pavements
Main variable	$AGE_{Surflayer}$ (based on 10t cumulative axle loading)	10t cumulative axle loading ($AL_{i,j,k}$)	8t cumulative axle loading (YE4)
Additional data needed	- Distress index DI - Coefficient a based on pavement category	Coefficients $a_{j,k}$, $b_{j,k}$, & $c_{j,k}$ based on pavement category	- Pavement structure (structural number SNP, thickness of new and old layers HSNEW & HSOLD) - deflection DEF - percentage of cracking before rehabilitation PCRA, PCRW - AGE - Construction quality & maintenance (CDS, CMOD, CRT, CRP)
Calibration	Calibration of the general model: $K_{i,j}$	Adaptation of initial state and slope through coefficients $\alpha_{i,j,k}$ & $\beta_{i,j,k}$	Calibration coefficients for each submodel: K_{cia}, K_{ciw}, K_{cpa}, K_{cpw}

The main advantage of the given Austrian and German models is their simplicity and that they are based on just few data items. This means that, if properly calibrated, they may be applied for pavement management analysis even in cases where not much data is available.

Contrary, the HDM-4 model is much more complex and requires significant amount of data related to pavement structure, age and construction quality and maintenance. The main advantage of HDM-4 model is its comprehensiveness and possibility to calibrate each of the sub-models included.

3.4 Implementation of laboratory calibrated EPF into dTIMS CT

In the context of ***InteMat4PMS*** the performance prediction is realized by using laboratory calibrated EPF, which are linked to possible maintenance treatments and which are optimized under conditional or budgetary constraints. The principal items – including the implementation of the EPF and the calibration procedure – that need to be defined are (Deighton, 2012):

- Database structure (perspectives and attributes)
- Analysis set including
  - Analysis variables (annual, dynamic, static and compilation)
  - Treatment catalogue
  - Time frames for analysis
  - Benefit/cost analysis and optimization settings

3.4.1 Database structure

Based on the pre-selected EPF, input parameters, available data and information, different data tables (perspectives) with different properties (point information, section information, historic information, etc.) need to be defined and linked together. The following Table 2 gives an overview of the different data tables used in dTIMS CT application.

Table 2: Database structure of dTIMS CT application

Perspective	**Data and information**
Road	Net information and inventory
Pavement	pavement construction information
Geometry	cross section information
Traffic	traffic information
Condition	pavement condition data and information
PM-analysis	master perspective for LCA/LCCA analysis and EPF information

Each single table or perspective contains a high number of table fields or attributes, which are used to describe the different properties of the different road characteristics as well as the parameters for the EPF. These attributes are linked to numerical values, text information, dates, Boolean information and provide the basis for the concurrent transformation of all relevant information into the master table.

A detailed list of all perspectives and attributes in the different tables (perspectives) can be taken from Annex A.

3.4.2 Analysis set

The analysis set is the core of LCA/LCCA in dTIMS CT and defines how strategies are generated. The analysis set brings together all analysis objects and is the basis for the integration of laboratory calibrated EPF into LCA/LCCA.

(a) Analysis variables

For the practical integration of EPF different Analysis Variables need to be defined. Analysis Variables are a method of predicting how a variable will behave over time. There are four types of Analysis Variables (Deighton, 2009):

1. Static analysis variable:
   The value of this variable does not change during an analysis. It can be any attribute in the master perspective and only those. An example is administrative jurisdiction of a road (e.g., Provincial, District etc.)
2. Dynamic analysis variable:
   The value can change only when a treatment is applied. Initial value can be derived from an attribute in the master perspective or an expression. An example is the road width which is derived from an attribute and changes when a widening treatment is applied. Another example is a flag used for triggering which is derived from an expression and is set when a particular treatment is applied.
3. Annual analysis variable:
   The value of this variable can change every year in the analysis period and when a treatment is applied. Initial value can be derived from an attribute in the master perspective or an expression. An example is traffic volume derived from an attribute and incremented each year by a growth rate. Another example is the calibrated EPF index derived from an expression combining different input parameters and recalculated yearly by the same expression following the calculation of the other input parameters (e.g. ESAL).
4. Compilation analysis variable:
   The value is calculated once for a strategy at the end of the analysis period. It is defined only by an expression using a new set of built-in functions. It can be used to calculate values helpful for rejecting a strategy, as a parameter in the optimization stage, or for reporting purposes. An example of each is the B/C ratio of a treatment strategy, the present value of agency costs over the analysis period, or the internal rate of return of a treatment strategy.

All variables within the analysis set have to be described by expressions, which include the mathematical formulation of the performance prediction. These expressions return a numerical value of each single year in the analysis period. For the implementation of EPF into an analysis set the following steps have to be carried out:

- Definition of EPF-attribute:
  The EPF-attribute represents the condition attribute for which the pre-selected EPF will be calculated (e.g. cracking, rutting)
- Input Value:
  The Input Value is the starting point of the EPF at the beginning of the analysis period, hence the starting point of the prediction. This value has to be in accordance with the actual condition or the condition extrapolated from the last condition measurement.
- Expression:
  The expression is the mathematical formulation of the prediction curve. At least, it

includes one single time dependent parameter for the modeling of the time dependent change. This can be either the age of the pavement or the traffic load in form of ESAL. Usually, the EPF consists of more than one input variables, which have to be defined prior to incorporating the mathematical function of the EPF.

- Calculation order:
  The calculation order has to be defined in accordance with the calculation of the input parameters of the EPF. E.g. the time-dependent change of the traffic load has to be calculated before the values are used for the calculation of the yearly EPF values.

Table 3 gives an overview of the different analysis variables to be used to represent the different parameters within the LCA/LCCA. The detailed properties of all analysis variables can be taken from Annex A.

Table 3: Parameters and analysis variables in dTIMS CT application

Parameter	Analysis variable type
Age	Annual analysis variable
Traffic (load repetitions)	Annual analysis variable
Condition (cracking)	Annual analysis variable
Model parameters	Static or dynamic analysis variable
Calibration factors	Dynamic analysis variable
Yearly treatment costs	Annual analysis variable
Total treatment strategy costs	Compilation analysis variable
Benefit treatment strategy	Compilation analysis variable

(b) Treatment catalogue

For the comparison of the behaviour of the three different laboratory calibrated EPF the time when the first maintenance treatment becomes necessary is an essential result. Thus, for the purpose of demonstration, the treatment catalogue was reduced to one single major treatment with the properties shown in Table 4. The detailed properties of the treatment can be taken from Annex A as well.

Table 4: Properties of major treatment in dTIMS CT application

Property	Description
Category of treatment	Major or heavy maintenance treatment
Type of treatment	Replacement of surface layer and binder course
Costs	20 €/m^2
Trigger	Cracking rate > 10%
Reset	Cracking = 0%, AGE = 0, all other parameters will not change

(c) Time frame for analysis

As starting point for the analysis the year of the last condition measurement is selected. The end year of analysis is defined by a time frame of 20 years. This time frame guarantees the application of at least one major maintenance treatment within the analysis period. The analysis intervals are set to a single year interval for the whole analysis period.

(d) Benefit-cost analysis and optimization settings

For the practical execution of benefit/cost analysis the benefit is defined in form of the traffic weighted "Area Under the Curve" value. It is calculated by summing the present value of the difference between the cracking rate resulting from the maintenance treatment strategy and the cracking rate for the do-nothing curve for each year in the analysis period.

Based on the present value of the total costs of each single maintenance treatment strategy and the corresponding technical benefit the benefit/cost ratio was calculated in addition and used as optimization criteria (target function). Because of the short road network the optimization is defined without additional (budgetary) restrictions.

A detailed list of all properties and settings for the optimization scenario can be taken from Annex A.

3.5 Testing functionality, execution and provision of results

In the context of testing the functionality of the implemented functions within the dTIMS CT application the debugger functionality was used. Figure 10 shows a screenshot of the dTIMS debugger. In parallel, the output of the calculations was compared with calculations carried out using MS Excel.

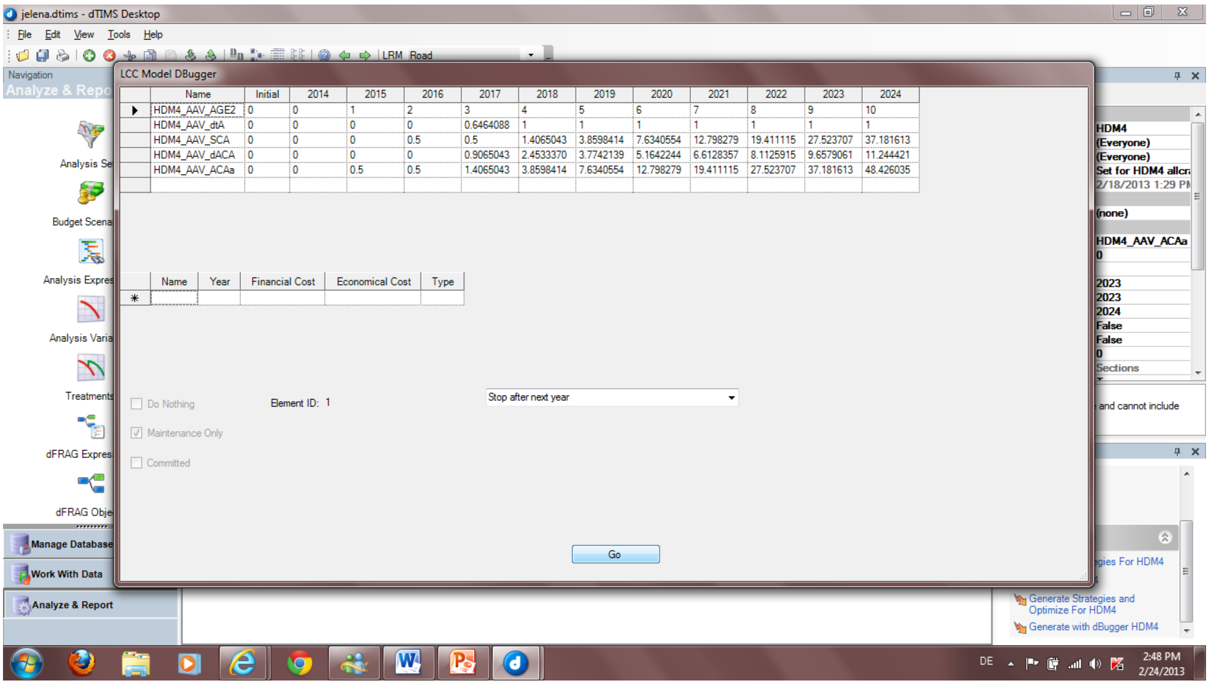

Figure 10: dTIMS debugger

After a positive testing phase the LCA/LCCA can be executed for all sections to be analyzed. The execution of LCA/LCCA is carried out in two steps, where the first step is the generation of the list of maintenance treatment strategies of each individual analysis section. The output of this step is a section related table, where the yearly values of all analysis variables can be viewed including the behavior of the calibrated and non-calibrated EPF but also the costs and benefit of the selected maintenance treatment.

Within the second step, the system tries to find the optimum solution over all maintenance treatment strategies and over all analysis sections under the given requirements. Because of no budgetary constraints, the optimum solution in the in dTIMS CT application is the maintenance treatment strategy with the highest benefit (last point on the efficiency frontier, see also Figure 5 strategy S3).

4 References

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dTIMS CT Perspective Report

Printed On: 3/27/2013 5:14:40 AM

Name	Cross_section
Description	Cross section information
Modified By	
Modified On	2/27/2013
Type	Section
Connect String	

Attributes For Cross_section

Name	Description	Modified By	Modified On	Perspective	Type
Number_lanes	Number of lanes	1111	2/27/2013	Cross_section	Integer
Width_total	Total width of carriageway	1111	2/27/2013	Cross_section	Double
Width_lane	Width of lane (heavy vehicle lane)	1111	2/27/2013	Cross_section	Double

Name	Other
Description	Other PMS relevant data
Modified By	
Modified On	2/27/2013
Type	Section
Connect String	

Name	Pavement
Description	Pavement construction data
Modified By	
Modified On	2/27/2013
Type	Section
Connect String	

Attributes For Pavement

Name	Description	Modified By	Modified On	Perspective	Type
L1_thickness	Layer 1 (top) thickness (cm)	1111	2/27/2013	Pavement	Double
L1_year	Layer 1 construction year	1111	2/27/2013	Pavement	Integer
L1_material	Layer 1 material	1111	2/27/2013	Pavement	Text
L2_material	Layer 2 material	1111	2/27/2013	Pavement	Text
L2_thickness	Layer 2 thickness (cm)	1111	2/27/2013	Pavement	Double
L2_year	Layer 2 construction year	1111	2/27/2013	Pavement	Integer
L3_material	Layer 3 material	1111	2/27/2013	Pavement	Text
L3_thickness	Layer 3 thickness (cm)	1111	2/27/2013	Pavement	Double
L3_year	Layer 3 construction year	1111	2/27/2013	Pavement	Integer
L4_material	Layer 4 material	1111	2/27/2013	Pavement	Text
L4_thickness	Layer 4 thickness (cm)	1111	2/27/2013	Pavement	Double
L4_year	Layer 4 construction year	1111	2/27/2013	Pavement	Integer
L5_material	Layer 5 material	1111	2/27/2013	Pavement	Text

Name	Description	Modified By	Modified On	Perspective	Type
L5_thickness	Layer 5 thickness (cm)	1111	2/27/2013	Pavement	Double
L5_year	Layer 5 construction year	1111	2/27/2013	Pavement	Integer
SN	Structural number	1111	2/27/2013	Pavement	Double

Name	PM_analysis
Description	Analysis sections
Modified By	
Modified On	12/18/2012
Type	Section
Connect String	

Attributes For PM_analysis

Name	Description	Modified By	Modified On	Perspective	Type
A_TRF_N_PID	Austrian model number load repitions at PI D in mio	1111	3/1/2013	PM_analysis	Double
A_cracking_Xf	Austrian model scaling factor Xf	1111	3/1/2013	PM_analysis	Double
HDM4_allcrack_CRP	HDM4 model retardation of crack progression due to maintenance (years)	1111	2/28/2013	PM_analysis	Double
HDM4_allcracking_ACAa	HDM4 model all cracking at the beginning of the analysis year	1111	2/28/2013	PM_analysis	Double
HDM4_allcracking_CDS	HDM4 model constr. defects indicator for bituminous surfacing	1111	2/28/2013	PM_analysis	Double
HDM4_allcracking_CRT	HDM4 model crack retardation time due to maintenance (years)	1111	2/28/2013	PM_analysis	Double
HDM4_allcracking_eq18_calibration_K_cia	HDM4 model calibration factor for all cracking in HDM4 for unbound base, original surfacing	1111	2/28/2013	PM_analysis	Double
HDM4_allcracking_eq21_calibration_K_ciw	HDM4 model calibration factor for wide cracking in HDM4	1111	2/28/2013	PM_analysis	Double
HDM4_Pavement_type	HDM4 model pavement type	1111	2/28/2013	PM_analysis	Text
HDM4_widecracking_ACWa	HDM4 model wide cracking at the beginning of the analysis year	1111	2/28/2013	PM_analysis	Double
HDM4_widecracking_ICW	HDM4 model time to initiation of wide structural cracking	1111	2/28/2013	PM_analysis	Double
DEF_coef_01	Default coefficient 0 to 1	1111	2/28/2013	PM_analysis	Double
DEF_coeff_txt	Default coefficient for text	1111	2/28/2013	PM_analysis	Text
HDM4_allcrack_SNP	HDM4 model average annual adjusted Structural Number (cm)	1111	2/28/2013	PM_analysis	Double
HDM4_Allcracking_ICA	HDM4 model ICA parameter	1111	2/28/2013	PM_analysis	Double
HDM4_coeff_value	HDM4 model attribute for default coefficients for structural cracking	1111	2/28/2013	PM_analysis	Double
G_COND_N_PID	German model number load repitions at PI D in mio	1111	3/1/2013	PM_analysis	Double

Name	Description	Modified By	Modified On	Perspective	Type
G_COND_Xf	German model scaling factor Xf	1111	3/1/2013	PM_analysis	Double
HDM4_COND_N_PID	HDM4 model number load repitions at PI D in mio	1111	3/1/2013	PM_analysis	Double
HDM4_COND_Xf	HDM4 model scaling factor Xf	1111	3/1/2013	PM_analysis	Double
A_PAV_DI	Austrian model design index	1111	3/1/2013	PM_analysis	Double
G_COND_MP_a	Germany model parameter a	1111	12/18/2012	PM_analysis	Double
G_COND_MP_b	Germany model parameter b	1111	12/18/2012	PM_analysis	Double
G_COND_MP_c	Germany model parameter c	1111	12/18/2012	PM_analysis	Double
G_TRF_ALtZEB	Germany traffic cumulative axle load in mio 100kN at tZEB	1111	12/18/2012	PM_analysis	Double
G_COND_z_cracking_bZEB	Germany cracking rate at bZEB	1111	12/18/2012	PM_analysis	Double
G_COND_z_cracking_tZEB	Germany cracking rate at tZEB	1111	12/18/2012	PM_analysis	Double
G_COND_MP_alpha	Germany model parameter alpha	1111	12/18/2012	PM_analysis	Double
G_COND_MP_beta	Germany model parameter beta	1111	12/18/2012	PM_analysis	Double
DEF_costbenefit	Default value for costs and benefit	1111	12/18/2012	PM_analysis	Double
A_cracking_MP_a	Austrian model parameter a	1111	3/1/2013	PM_analysis	Double
A_cracking_KF	Austrian model calibration factor	1111	3/1/2013	PM_analysis	Double
A_TP_crack_measured	Austrian model cracking rate at last measurement	1111	3/1/2013	PM_analysis	Double
A_TP_crack_actual	Austrian model cracking rate actual year	1111	3/1/2013	PM_analysis	Double
INV_PAV_AGE	Age since the last overlay	1111	2/28/2013	PM_analysis	Double
INV_PAV_CBR	California Bearing Capacity (%)	1111	2/28/2013	PM_analysis	Double
INV_TRF_ESAL_80kN	Cummulative traffic load ESAL mil 80 kN	1111	2/28/2013	PM_analysis	Double
INV_TRF_ESAL100kN	Cummulative traffic load ESAL mil 100kN	1111	2/28/2013	PM_analysis	Double
INV_PAV_SN	Structural Number (cm)	1111	2/28/2013	PM_analysis	Double

Name	Road
Description	Road network
Modified By	
Modified On	12/18/2012
Type	Section
Connect String	

Name	Traffic
Description	Traffic data
Modified By	
Modified On	2/27/2013
Type	Section
Connect String	

Attributes For Traffic

Name	Description	Modified By	Modified On	Perspecti ve	Type
AADT_total	Total AADT	1111	2/27/2013	Traffic	Long
AADT_trucks	AADT trucks greater 3.5 tons	1111	2/27/2013	Traffic	Long

dTIMS CT Analysis Variables Report

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Name	A_AAV_AGE_age
Type	Annual
Description	Austrian model age
Modified By	1111
Modified On	3/1/2013

Curves For A_AAV_AGE_age

Filter	Expression
(none)	A_AAV_n_AGE_age

Name	A_AAV_COND_TP_crack
Type	Annual
Description	Austrian model cracking rate
Modified By	1111
Modified On	3/1/2013

Curves For A_AAV_COND_TP_crack

Filter	Expression
(none)	A_AAV_n_COND_TP_cracking

Name	A_AAV_COND_X_TP_crack
Type	Annual
Description	Austrian model calibrated cracking
Modified By	1111
Modified On	3/1/2013

Name	A_DAV_COND_MP_a
Type	Dynamic
Description	Austrian model parameter a
Modified By	1111
Modified On	2/27/2013

Name	G_AAV_COND_z_cracking_t
Type	Annual
Description	Germany cracking z
Modified By	1111
Modified On	12/18/2012

Curves For G_AAV_COND_z_cracking_t

Filter	Expression
(none)	G_AAV_n_COND_z_cracking_t

Name	G_AAV_TRF_ALt
Type	Annual
Description	Germany cumulative axle loads 100kN
Modified By	1111
Modified On	12/18/2012

Curves For G_AAV_TRF_ALt

Filter	Expression
(none)	G_AAV_n_TRF_ALt

Name	G_DAV_COND_MP_alpha
Type	Dynamic
Description	Germany model parameter alpha
Modified By	1111
Modified On	12/18/2012

Name	G_DAV_COND_MP_beta
Type	Dynamic
Description	Germany model parameter beta
Modified By	1111
Modified On	12/18/2012

Name	G_DAV_COND_MP_c
Type	Dynamic
Description	Germany model parameter c
Modified By	1111
Modified On	12/18/2012

Name	HDM4_AAV_AGE_age2
Type	Annual
Description	HDM4 model age2 variable
Modified By	1111
Modified On	3/1/2013

Curves For HDM4_AAV_AGE_age2

Filter	Expression
(none)	HDM4_AAV_aN_AGE2

Name	HDM4_AAV_COND_ACAa
Type	Annual
Description	HDM4 model cracking at the beginning of the analysis year
Modified By	1111
Modified On	3/1/2013

Curves For HDM4_AAV_COND_ACAa

Filter	Expression
(none)	HDM4_AAV_aN_ACAa

Name	HDM4_AAV_COND_ACWa
Type	Annual
Description	HDM4 model wide cracking at the beginning of the analysis year
Modified By	1111
Modified On	3/1/2013

Curves For HDM4_AAV_COND_ACWa

Filter	Expression
(none)	HDM4_AAV_aN_ACWa

Name	HDM4_AAV_COND_dACA
Type	Annual
Description	HDM4 model yearly increase of ACA
Modified By	1111
Modified On	3/1/2013

Curves For HDM4_AAV_COND_dACA

Filter	Expression
(none)	HDM4_AAV_aN_dACAa

Name	HDM4_AAV_COND_dACW
Type	Annual
Description	HDM4 model yearly increase of ACW
Modified By	1111
Modified On	3/5/2013

Curves For HDM4_AAV_COND_dACW

Filter	Expression
(none)	HDM4_AAV_aN_dACWa

Name	HDM4_AAV_COND_dACW_gen
Type	Annual
Description	HDM4 model yearly increase of ACW general
Modified By	1111
Modified On	3/5/2013

Curves For HDM4_AAV_COND_dACW_gen

Filter	Expression
(none)	HDM4_AAV_aN_dACWa_gen

Name	HDM4_AAV_COND_dtA
Type	Annual
Description	HDM4 model dtA variable
Modified By	1111
Modified On	3/1/2013

Curves For HDM4_AAV_COND_dtA

Filter	Expression
(none)	HDM4_AAV_aN_dtA

Name	HDM4_AAV_COND_dtW
Type	Annual
Description	HDM4 model dtW variable
Modified By	1111
Modified On	3/1/2013

Curves For HDM4_AAV_COND_dtW

Filter	Expression
(none)	HDM4_AAV_aN_dtW

Name	HDM4_AAV_COND_SCA
Type	Annual
Description	HDM4 model variable based on ACAa
Modified By	1111
Modified On	3/1/2013

Curves For HDM4_AAV_COND_SCA

Filter	Expression
(none)	HDM4_AAV_aN_SCA

Name	HDM4_AAV_COND_SCW
Type	Annual
Description	HDM4 model variable based on ACWa
Modified By	1111
Modified On	3/1/2013

Curves For HDM4_AAV_COND_SCW

Filter	Expression
(none)	HDM4_AAV_aN_SCW

Name	S_AAV_CST_treatmentyearly
Type	Annual
Description	Yearly treatment costs
Modified By	1111
Modified On	2/27/2013

Curves For S_AAV_CST_treatmentyearly

Filter	Expression
(none)	AAV_n_CST_treatmentyearly

Name	S_CAV_BEN_benefitAUC
Type	Compilation
Description	Benefit area under the curve
Modified By	1111
Modified On	2/27/2013

Curves For S_CAV_BEN_benefitAUC

Filter	Expression
(none)	CAV_n_BEN_benefitAUC

Name	S_CAV_CST_totalcosts
Type	Compilation
Description	Total costs treatment strategy
Modified By	1111
Modified On	2/27/2013

Curves For S_CAV_CST_totalcosts

Filter	Expression
(none)	CAV_n_CST_totalcosts

dTIMS CT Treatments Report

Printed On: 3/27/2013 5:15:21 AM

Name	Repl_surf_bind
Description	Replacement surface layer and binder
Modified By	1111
Modified On	3/27/2013
Perspective	PM_analysis
Type	Major
Interval Year	0
Trigger Filter	TRT_n_TRG_G_Repl_surf_bind
Budget Category	Maint
Trigger Template	Both
Can Initiate Strategy	True
Apply After Initial	False
Override Budget Category	False

Costs For Repl_surf_bind

Filter	Economical Cost	Financial Cost
(none)	(none)	TRT_n_CST_Repl_surf_bind

Resets For Repl_surf_bind

Filter	Expression	Variable
(none)	TRT_n_RV_0	A_AAV_AGE_age
(none)	TRT_n_RV_0	HDM4_AAV_COND_dtA
(none)	TRT_n_RV_0	G_AAV_TRF_ALt
(none)	TRT_n_RV_COND_MP_alpha_Recon	G_DAV_COND_MP_alpha
(none)	TRT_n_RV_COND_MP_beta_Recon	G_DAV_COND_MP_beta
(none)	AAV_n_CST_treatmenty early	S_AAV_CST_treatmenty early

dTIMS CT Budget Scenario Report

Printed On: 3/27/2013 5:15:55 AM

Name	Scenario_1
Description	Standardscenario
Modified By	
Modified On	3/27/2013
Analysis Set	InteMat4PMS_1
Type	Maximize benefits using IBC
Filter	(none)
Include Do Nothing	True
Include Committed	False
Cost Variable	S_CAV_CST_totalcosts
Benefit Variable	S_CAV_BEN_benefitAUC
Exclude	
MultiPass	True
Use Total Budget	False
Result	The Optimal solution was found

Budgets For Scenario_1

Year	Total	Maint
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		
2021		
2022		
2023		
2024		
2025		
2026		
2027		
2028		
2029		
2030		
2031		
2032		

dTIMS CT Analysis Set Report

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Name	InteMat4PMS_1
Description	Set 1 for InteMat4PMS
Modified By	
Modified On	3/27/2013
Perspective	PM_analysis
Filter	(none)
Strategy Perspective	InteMat4PMS_1
Strategy Database	C:\PMS_Consult\01_Projekte\11-004_ERANET_InteMat4PMS\dTIMS_Intemat4PMS_Alfred\InteMat4PMS_1.mdb
Traffic Analysis Variable	G_AAV_TRF_ALt
Condition Analysis Variable	A_AAV_COND_TP_crack
Start of Analysis	2013
End of Analysis	2038
End Treatment Application Year	2033
End Performance Plotting Year	2033

Analysis Variables For InteMat4PMS_1

Name	Description	Modified By	Modified On	Type	Kept
A_AAV_AGE_age	Austrian model age	1111	3/1/2013	Annual	✓
A_DAV_COND_MP_a	Austrian model parameter a	1111	2/27/2013	Dynamic	✓
A_AAV_COND_TP_crack	Austrian model cracking rate	1111	3/1/2013	Annual	✓
G_DAV_COND_MP_alpha	Germany model parameter alpha	1111	12/18/2012	Dynamic	✓
G_DAV_COND_MP_beta	Germany model parameter beta	1111	12/18/2012	Dynamic	✓
G_DAV_COND_MP_c	Germany model parameter c	1111	12/18/2012	Dynamic	✓
G_AAV_TRF_ALt	Germany cumulative axle loads 100kN	1111	12/18/2012	Annual	✓
G_AAV_COND_z_cracking_t	Germany cracking z	1111	12/18/2012	Annual	✓
HDM4_AAV_AGE_age2	HDM4 model age2 variable	1111	3/1/2013	Annual	✓
HDM4_AAV_COND_dtA	HDM4 model dtA variable	1111	3/1/2013	Annual	✓
HDM4_AAV_COND_SCA	HDM4 model variable based on ACAa	1111	3/1/2013	Annual	✓
HDM4_AAV_COND_dACA	HDM4 model yearly increase of ACA	1111	3/1/2013	Annual	✓
HDM4_AAV_COND_dtW	HDM4 model dtW variable	1111	3/1/2013	Annual	✓
HDM4_AAV_COND_SCW	HDM4 model variable based on ACWa	1111	3/1/2013	Annual	✓
HDM4_AAV_COND_dACW_gen	HDM4 model yearly increase of ACW general	1111	3/5/2013	Annual	✓
HDM4_AAV_COND_dACW	HDM4 model yearly increase of ACW	1111	3/5/2013	Annual	✓
HDM4_AAV_COND_ACAa	HDM4 model cracking at the beginning of the analysis year	1111	3/1/2013	Annual	✓
HDM4_AAV_COND_ACWa	HDM4 model wide cracking at the beginning of the analysis year	1111	3/1/2013	Annual	✓
S_AAV_CST_treatmentyearly	Yearly treatment costs	1111	2/27/2013	Annual	✓
S_CAV_CST_totalcosts	Total costs treatment strategy	1111	2/27/2013	Compilation	✓

Name	Description	Modified By	Modified On	Type	Kept
S_CAV_BEN_benefit AUC	Benefit area under the curve	1111	2/27/2013	Compilation	✓

Treatments For InteMat4PMS_1

Name	Description	Modified By	Modified On	Perspective	Type	Int. Year	Trig. Filt.	Bud. Cat.	Template	Can Init.	After Init.
Repl_surf_bind	Replacement surface layer and binder	1111	3/27/2013	PM_analysis	Major	0	TRT_n_TRG_G_Repl_surf_bind	Maint	Both	✓	

dTIMS CT Analysis Expression Report

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Name	A_AAV_n_AGE_age
Description	Austrian model age
Modified By	
Modified On	3/1/2013
Type	Double
The Expression	A_AAV_AGE_age + 1.0

Name	A_AAV_n_COND_TP_cracking
Description	Austrian model TP cracking
Modified By	
Modified On	3/1/2013
Type	Double
The Expression	EXP(-3.60517 + A_DAV_COND_MP_a * A_AAV_AGE_age + LOG(A_AAV_AGE_age + 0.01) - 0.5 * LOG(PM_analysis->A_PAV_DI + 0.01))

Name	AAV_n_CST_treatmentyearly
Description	Yearly treatment costs
Modified By	
Modified On	12/18/2012
Type	Double
The Expression	GST_COST_F

Name	CAV_n_BEN_benefitAUC
Description	Benefit area under the curve
Modified By	
Modified On	12/18/2012
Type	Double
The Expression	GET4CAV_PVDIFF (G_AAV_COND_z_cracking_t,100,G_AAV_TRF_ALt,1)

Name	CAV_n_CST_totalcosts
Description	Total costs of treatment strategy
Modified By	
Modified On	12/18/2012
Type	Double
The Expression	GET4CAV_PV(S_AAV_CST_treatmentyearly)

Name	G_AAV_n_COND_X_z_cracking_t
Description	German model calibrated cracking
Modified By	
Modified On	3/1/2013
Type	Double
The Expression	PM_analysis->G_COND_Xf * G_AAV_COND_z_cracking_t

Name	G_AAV_n_COND_z_cracking_t
Description	Germany cracking model z
Modified By	
Modified On	12/18/2012
Type	Double
The Expression	MIN(100.0,G_DAV_COND_MP_alpha + (G_DAV_COND_MP_beta / 10.0 ** 10.0) * G_AAV_TRF_ALt ** G_DAV_COND_MP_c)

Name	G_AAV_n_TRF_ALt
Description	Germany cumulative axle load 100kN
Modified By	
Modified On	3/5/2013
Type	Double
The Expression	G_AAV_TRF_ALt + 2.0

Name	G_DP_n_COND_MP_alpha
Description	Germany model parameter alpha
Modified By	
Modified On	12/18/2012
Type	Double
The Expression	IF(PM_analysis->G_TRF_ALtZEB = 0.0,0.0,PM_analysis->G_COND_MP_a * PM_analysis->G_COND_z_cracking_bZEB / PM_analysis->G_COND_z_cracking_tZEB)

Name	G_DP_n_COND_MP_beta
Description	Germany model parameter beta
Modified By	
Modified On	3/1/2013
Type	Double
The Expression	IF(PM_analysis->G_COND_z_cracking_bZEB = 0.0,PM_analysis->G_COND_MP_b,(PM_analysis->G_COND_z_cracking_bZEB - PM_analysis->G_COND_MP_alpha) / (PM_analysis->G_TRF_ALtZEB ** PM_analysis->G_COND_MP_c) * 10.0 ** 10.0)

Name	G_DP_n_COND_z_cracking_tZEB
Description	Germany z cracking t ZEB
Modified By	
Modified On	12/18/2012
Type	Double
The Expression	PM_analysis->G_COND_MP_a + (PM_analysis->G_COND_MP_b / 10.0 ** 10.0) * PM_analysis->G_TRF_ALtZEB ** PM_analysis->G_COND_MP_c

Name	HDM4_AAV_aN_ACAa
Description	HDM4 model all cracking ACAa
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	MAX(0.5, HDM4_AAV_COND_ACAa + HDM4_AAV_COND_dACA)

Name	HDM4_AAV_aN_ACWa
Description	HDM4 model wide cracking ACWa
Modified By	
Modified On	3/5/2013
Type	Double
The Expression	MAX(0.5, HDM4_AAV_COND_ACWa + HDM4_AAV_COND_dACW)

Name	HDM4_AAV_aN_AGE2
Description	HDM4 model age2
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	HDM4_AAV_AGE_age2 + 1.0

Name	HDM4_AAV_aN_dACAa
Description	HDM4 model analysis variable for dACAa
Modified By	
Modified On	3/1/2013
Type	Double
The Expression	1.0 * (PM_analysis->HDM4_allcrack_CRP/PM_analysis->HDM4_allcracking_CDS) * 1.0 * ((1.0 * XTAB (HDM4_coeff_Pro_allcracking, 'a0', PM_analysis->HDM4_Pavement_type, 1.84) * XTAB (HDM4_coeff_Pro_allcracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.45) * HDM4_AAV_COND_dtA + HDM4_AAV_COND_SCA ** XTAB (HDM4_coeff_Pro_allcracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.45)) ** (1.0 / XTAB (HDM4_coeff_Pro_allcracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.45)) - HDM4_AAV_COND_SCA)

Name	HDM4_AAV_aN_dACWa
Description	HDM4 model dACWa
Modified By	
Modified On	3/5/2013
Type	Double
The Expression	MIN(HDM4_AAV_COND_ACAa + HDM4_AAV_COND_dACA - HDM4_AAV_COND_ACWa,HDM4_AAV_COND_dACW_gen)

Name	HDM4_AAV_aN_dACWa_gen
Description	HDM4 model analysis variable for dACWa general
Modified By	
Modified On	3/5/2013
Type	Double
The Expression	1.0 * (PM_analysis->HDM4_allcrack_CRP / PM_analysis->HDM4_allcracking_CDS) * 1.0 * ((1.0 * XTAB (HDM4_coeff_Pro_widecracking, 'a0', PM_analysis->HDM4_Pavement_type, 2.94) * XTAB (HDM4_coeff_Pro_widecracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.56) * HDM4_AAV_COND_dtW + HDM4_AAV_COND_SCW ** XTAB (HDM4_coeff_Pro_widecracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.56)) ** (1.0 / XTAB (HDM4_coeff_Pro_widecracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.56)) - HDM4_AAV_COND_SCW)

Name	HDM4_AAV_aN_dtA
Description	HDM4 model dtA value
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	MAX(0.0,MIN((HDM4_AAV_AGE_age2 - PM_analysis->HDM4_Allcracking_ICA),1.0))

Name	HDM4_AAV_aN_dtW
Description	HDM4 model dtW value
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	MAX(0.0,MIN((HDM4_AAV_AGE_age2 - PM_analysis->HDM4_widecracking_ICW),1.0))

Name	HDM4_AAV_aN_SCA
Description	HDM4 model SCA parameter
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	MIN(HDM4_AAV_COND_ACAa, 100.0 - HDM4_AAV_COND_ACAa)

Name	HDM4_AAV_aN_SCW
Description	HDM4 model SCW parameter
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	MIN(HDM4_AAV_COND_ACWa, 100.0 - HDM4_AAV_COND_ACWa)

Name	HDM4_DP_n_COND_allcrack_CRP
Description	HDM4 model retardation of cracking progression due to maintenance
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	1.0 - 0.12 * PM_analysis->HDM4_allcracking_CRT

Name	HDM4_DP_n_COND_allcrack_ICA_eq18
Description	HDM4 model time to initiation of all structural cracking (years) unbound base, original surfacing
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	PM_analysis->HDM4_allcracking_eq18_calibration_K_cia * ((PM_analysis->HDM4_allcracking_CDS) ** 2.0 * 4.21 * EXP (0.14*PM_analysis->HDM4_allcrack_SNP + (-17.1) * PM_analysis->INV_TRF_ESAL_80kN / (PM_analysis->HDM4_allcrack_SNP) ** 2.0) + PM_analysis->HDM4_allcracking_CRT)

Name	HDM4_DP_n_COND_widecrack_ICW
Description	HDM4 model time to initiation of wide structural cracking (years)
Modified By	
Modified On	3/1/2013
Type	Double
The Expression	PM_analysis->HDM4_allcracking_eq21_calibration_K_ciw * MAX((2.46 + 0.93 * PM_analysis->HDM4_Allcracking_ICA),0.0*PM_analysis->HDM4_Allcracking_ICA)

Name	HDM4_DP_n_PAV_allcrack_SNP
Description	HDM4 model SNP parameter
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	PM_analysis->INV_PAV_SN + 3.51 * LOG10(PM_analysis->INV_PAV_CBR) - 0.85 * (LOG10(PM_analysis->INV_PAV_CBR))** 2.0 - 1.43

Name	HDM4_IV_aN_AAV_dACAa
Description	HDM4 model initial value for dACAa
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	1.0 * (PM_analysis->HDM4_allcrack_CRP/PM_analysis->HDM4_allcracking_CDS) * 1.0 * ((1.0 * XTAB (HDM4_coeff_Pro_allcracking, 'a0', PM_analysis->HDM4_Pavement_type, 1.84) * XTAB (HDM4_coeff_Pro_allcracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.45) * HDM4_IV_aN_AAV_dtA + HDM4_IV_aN_AAV_SCA**XTAB (HDM4_coeff_Pro_allcracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.45))**(1.0/XTAB (HDM4_coeff_Pro_allcracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.45)) - HDM4_IV_aN_AAV_SCA)

Name	HDM4_IV_aN_AAV_dACWa
Description	HDM4 model Initial value for dACWa
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	1.0 * (PM_analysis->HDM4_allcrack_CRP/PM_analysis->HDM4_allcracking_CDS) * 1.0 * ((1.0 * XTAB (HDM4_coeff_Pro_widecracking, 'a0', PM_analysis->HDM4_Pavement_type, 2.94) * XTAB (HDM4_coeff_Pro_widecracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.56) * HDM4_IV_aN_AAV_dtW + HDM4_IV_aN_AAV_SCW**XTAB (HDM4_coeff_Pro_widecracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.56))**(1.0/XTAB (HDM4_coeff_Pro_widecracking, 'a1', PM_analysis->HDM4_Pavement_type, 0.56)) - HDM4_IV_aN_AAV_SCW)

Name	HDM4_IV_aN_AAV_dtA
Description	HDM4 model initial value for dtA
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	MAX(0.0,MIN((PM_analysis->INV_PAV_AGE - PM_analysis->HDM4_Allcracking_ICA),1.0))

Name	HDM4_IV_aN_AAV_dtW
Description	HDM4 model initial value for dtW
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	MAX(0.0,MIN((PM_analysis->INV_PAV_AGE - PM_analysis->HDM4_widecracking_ICW),1.0))

Name	HDM4_IV_aN_AAV_SCA
Description	HDM4 model initial value for SCA
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	MIN(PM_analysis->HDM4_allcracking_ACAa, 100.0 - PM_analysis->HDM4_allcracking_ACAa)

Name	HDM4_IV_aN_AAV_SCW
Description	HDM4 model initial value for SCW
Modified By	
Modified On	2/28/2013
Type	Double
The Expression	MIN(PM_analysis->HDM4_widecracking_ACWa, 100.0 - PM_analysis->HDM4_widecracking_ACWa)

Name	TRT_n_CST_Repl_surf_bind
Description	Costs for replacement surface layer and binder
Modified By	
Modified On	3/27/2013
Type	Double
The Expression	PM_analysis->Length * 1000.0 * 10.0 * 20.0

Name	TRT_n_RV_0
Description	Reset value 0
Modified By	
Modified On	3/27/2013
Type	Double
The Expression	0.0

Name	TRT_n_RV_COND_MP_alpha_Recon
Description	Reset value MP alpha reconstruction
Modified By	
Modified On	12/18/2012
Type	Double
The Expression	0.0

Name	TRT_n_RV_COND_MP_beta_Recon
Description	Reset value MP beta reconstruction
Modified By	
Modified On	12/18/2012
Type	Double
The Expression	0.0009

Name	TRT_n_TRG_G_Repl_surf_bind
Description	Trigger replacement surface and binder (german model)
Modified By	
Modified On	3/27/2013
Type	Boolean
The Expression	G_AAV_COND_z_cracking_t > 10.0 Or A_AAV_COND_TP_crack > 10.0 Or HDM4_AAV_COND_ACAa > 10.0