Integrated Asset Management Tool for Highway Infrastructure

Robert VEIT-EGERER
Head of Department
Vienna Consulting Engineers
Vienna, Austria
veit-egerer@vce.at

Monika WIDMANN
Project Manager
Vienna Consulting Engineers
Vienna, Austria
widmann@vce.at

Peter FURTNER
Vice President
Vienna Consulting Engineers
Vienna, Austria
furtner@vce.at

Rui LIMA
Civil Engineer
Vienna Consulting Engineers
Vienna, Austria
lima@vce.at

Summary

To enable proper and long-term maintenance planning for a huge and heterogeneous set of engineering structures (bridges, culverts, noise barriers, gantries) VCE developed an integrated life cycle management tool that offers tailored solutions with regard to the given location, involved materials, fabricates and the underlying design code at the time of construction. The core of this tool is formed by a probabilistic ageing model and a comprehensive cost model. Each structural member is represented by a generic ageing function, which is derived from the major sources of information reflecting impact on structural ageing (visual inspection/ numerical simulation/ structural monitoring and freight traffic progression). Furthermore the model incorporates VCE's 50 years of experience in the field of bridge inspections and structural health monitoring. Due to defined treatment-trigger-criteria a huge set of maintenance strategies is generated leading to an extensive optimization exercise. The final project output is composed by tailored maintenance plans for every structure.

Keywords: Remaining Lifetime, Decision Tools, Maintenance Strategies, Optimization.

1. Introduction

A considerable shift in state-of-the-art policy for structural maintenance has been observed in the recent past. Major aspects like

- Network level analysis (instead of single structure maintenance)
- Cross-asset maintenance
- and long-term scheduling instead of short term planning

represent a substantially broadened demand from infrastructure owners & operators.

The authors describe a development that incorporates these new key aspects into an integrated software solution - composed in a modular manner and enabling periodic modification, changes or improvements.

The paper presents a system for estimating the remaining lifetime of engineering structures in the course of roadways, analysing the structural design, processing the data of visual inspections and structural monitoring campaigns. The system also predicts the performance of structures depending on the strategies adopted for maintenance and repair. The methodology implemented in the system is based on the statistical analysis of a large database of structures, and consequently its response is realistic and empirically well-founded.

Parts of an existing highway network, that has already been analysed in the course of a comprehensive reference project (see [1]) served as a valuable basis throughout the entire development work (determination of proper algorithms, software programing, testing) of the presented asset management tool.

2. Process Scheme

A full overview on the developed approach is given in Fig. 1 by means of a flowchart – in order to perform long-term maintenance planning of a given network based on existing structural stock information.

In the beginning of an asset management analysis a study on the fundamentals is to be conducted regarding the usability and completeness of digital information. Probable data gaps can be closed by means of analog data from archives. Final uncertainties on structural specification, geometric properties, types of fabricates of certain members etc. should be covered with an on-site visit.

In the introduction it was already stated, that the Life Cycle Methodology is based on three main categories of evaluation:

- Visual Inspection (periodic surveys)
- Loading Conditions (underlying design code & real traffic loading)
- Field tests (Dynamic measurements, non-destructive testing)

This block-wise division of the analysis allows the user to appreciate the contribution of each piece of information in the overall result.

The core of the management tool is formed by a probabilistic ageing model and a comprehensive cost model that is tailored with regard to the given location, involved materials, fabricates etc. Each structural member is represented by a generic ageing function, which is derived from a so-called condition index based on the 3 listed categories of impact reflecting structural ageing (Visual Inspection / Numerical Simulation & Monitoring). While the Visual Inspection Indicator reflects the results from surveillances, checkings and assessments of structures, the Loading Indicator incorporates structural safety according to the applied design code, FE Simulations, field-test based loading models and freight traffic progression. The Monitoring Indicator considers available information from field tests (dynamic measurements, material tests etc.).

The shown stepwise process in Fig. 1 represents the ideal situation. In practice the listed methodological components are often lacking in terms of data (information) – being not available in a standardized/complete manner. For that reason the evaluation of available options followed by the adaptation of the given workflow becomes a necessity.

To cover the needs of real world applications the assessment method was developed under the premises of being applicable in any case, independent on the completeness of the information - reflecting the 3 defined methodological columns. Thus, proper weighting mechanisms and confidence intervals regarding the statistical distribution of the incorporated parameters were to be implemented depending on the quality, availability, completeness and reliability of the given information.

After considering all relevant information in terms of model parameters (merged and weighted into the resulting Condition Index) an initial life cycle prognosis is computed, representing the so-called “do-nothing” strategy. Subsequent calculations concerning maintenance and cost planning are based on this initial strategy. Due to defined treatment-trigger-criteria a huge set of maintenance strategies is generated leading to an extensive optimization exercise. The optimisation algorithms are mainly driven by the following criteria:

- Construction sections
- Structural condition requirements
- Minimisation of cost
- Maximisation of availability

Finally a cost and availability optimization with regard to traffic and construction site management is to be performed considering the usually existing pavement management concepts (again see [1]).

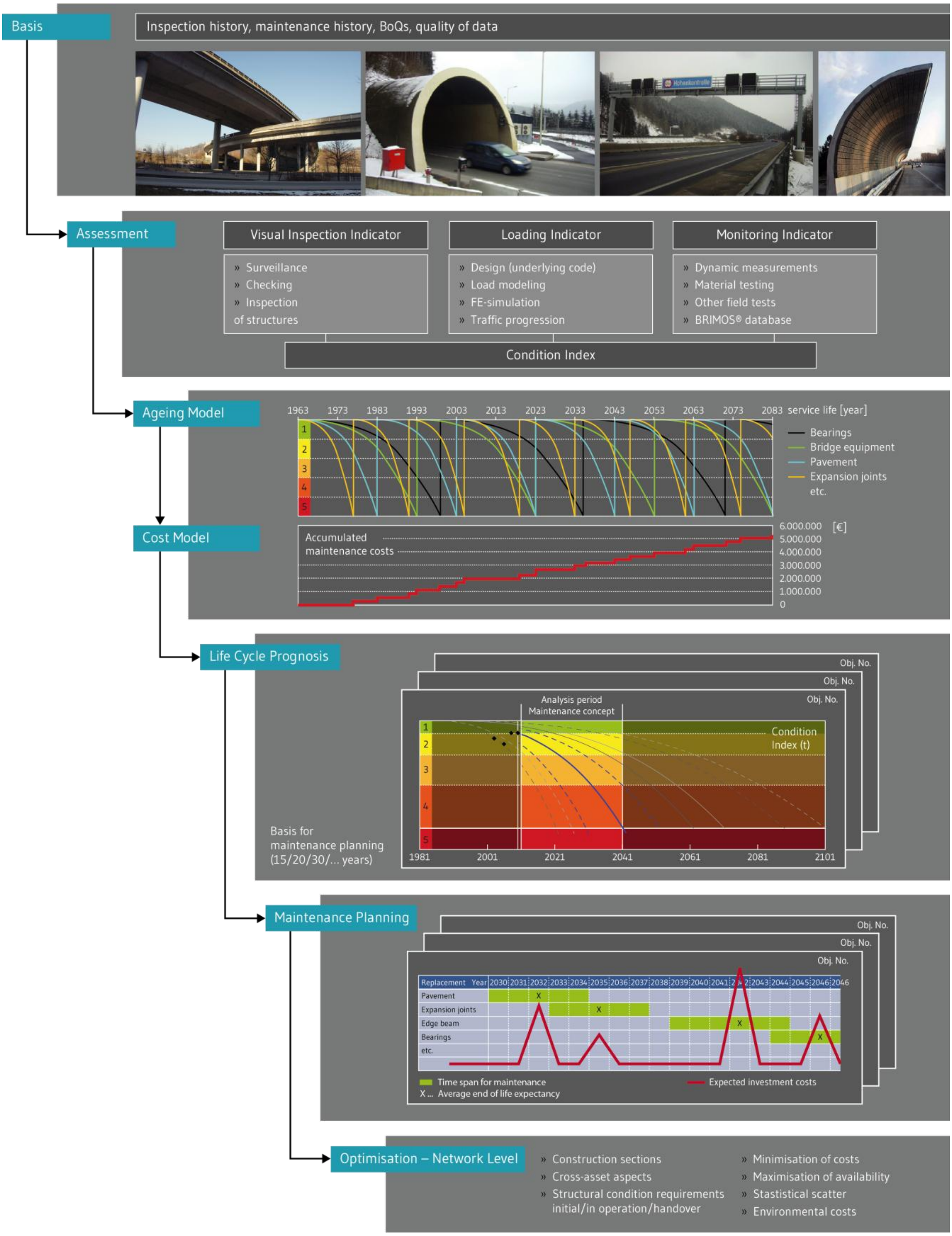

Fig. 1: Process scheme – from stock information to maintenance planning

3. Implementation

3.1 Objectives

With regard to the missing interface between BMS (Bridge Management Systems) & PMS (Pavement Management Systems) it was aspired to develop an integrated analysis and decision support tool that provides procedures and methods for optimised, holistic maintenance planning for highway infrastructure networks (engineering structures and pavement).

3.2 Softwareprototype

The software environment dTIMS_CT^{TM} (Version 8.6) from DEIGHTON (Deighton Total Infrastructure Management System) was chosen for the development of a new software application that provides a market-ready solution for lifecycle analysis of bridges and other engineering structures. The decision to use dTIMS CT^{TM} was strongly influenced by the fact that this software has been already used by the Austrian Federal Highway Company AFINAG for the maintenance management of pavement for many years. It is intended to interlink the newly developed bridge management system (BMS) and the existing pavement management system (PMS) in the same programming environment. However, it should be mentioned that the commercial software package itself is an empty programing environment where – depending on the application – a completely new and tailored software application can be developed. Within several years of research and development work (see [2] & [3]) a practical application for the maintenance management of engineering structures and cross-asset analysis respectively was created.

3.2.1 General description

A significant advantage of the chosen commercial software package is the open and customizable structure, providing a good basis for an asset management system. For this reason the available basics and requirements could be inserted directly into the system according to the required maintenance concept. The following general steps had to be executed:

- Setting of data format and input of data
- Implementation of an algorithm for data handling (calculation of input values for the analysis) and running the calculation algorithm
- Implementation of prognosis models for the condition of engineering structures, development of an extensive catalogue of measures, assessment algorithms for the condition of structural components (scaling, partial values and total values)
- Definition of the optimization problem
- Analysis (generation of strategies) and optimization

The analysis result is a section-related construction program or - more precisely - a suggestion for a maintenance strategy under predetermined conditions concerning the given budget or the demanded condition of the structures. In other words the results represent the basis (a decision support) for a subsequent engineering post-process.

In the following figures the overall assessment scheme for asset management on network level is illustrated in terms of process visualisations. The scheme is divided into two main processes:

- Flowchart 1: Input data with regard to Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) (as shown in Figure 2)
- Flowchart 2: LCA and LCCA itself, addressing the determination of maintenance schedules (composed by individual treatments) and linked to budget category-related optimization (as shown in Figure 3).

It is to be pointed out, that the shown assessment schemes utilise conventional ratings from structural inspection, which are usually available for every structure or can easily be provided. The given ratings are transformed into so-called health indices and are incorporated into comprehensive life cycle calculations. By this means the gap between rating and service life considerations is bridged.

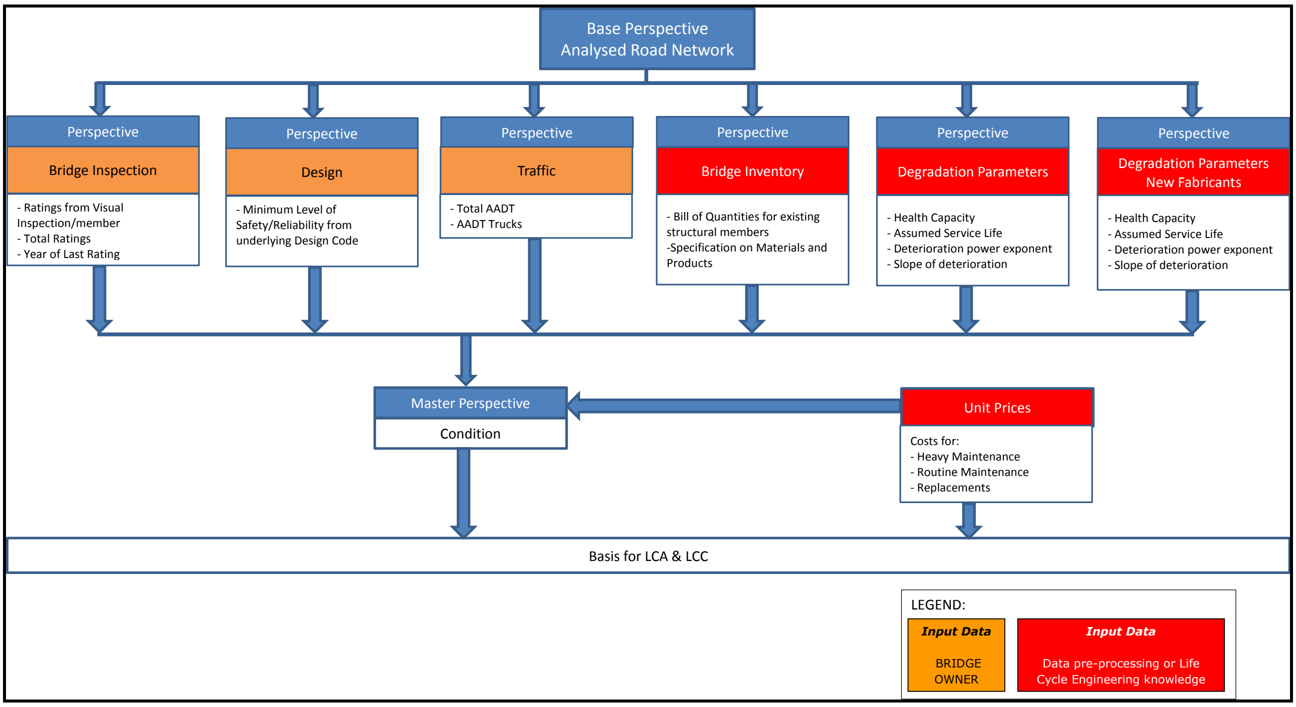

Fig. 2: Input data with regard to Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA)

3.2.2 Selected details on the modular composition

In the following the authors describe the stepwise development of the software prototype. This listing is to be understood as a general guidance through the performed development work without aiming for completeness or full detailing on every single step. These descriptions are also intended to support the traceability and understanding of the provided visualisations of the software and database architecture.

- Structuring, composition and programming of the different database modules (perspectives) for the main input data (incl. mathematical expressions):
  These are e.g. bridge inventory, condition data, categorization of relevant characteristics (cross sections/material/fabricates), distinction between old (existing) structural components and new state-of-the-art fabricates, design assumptions, traffic data and history on periodic structural surveillance over time.

Next steps to be mentioned are:

- Ageing models (partly depending on traffic impact) and the corresponding trigger criteria for different maintenance measures (incl. mathematical expressions)
- Weighting Mechanisms to consider the influence of different structural components on the overall structural ageing
- Definition of major/minor and routine measures and their analytical impact (improvement) on service life (incl. mathematical expressions)
- Comprehensive maintenance cost model
- Improvement of optimisation routines: refinement of implemented cost-benefit criteria, condition requirements for the operation phase and further explicitly demanded constraints
- Adaptation of the process environment due to analysing infrastructure networks instead of single structures
- Initial considerations on the duration of maintenance measures and their impact on corresponding potential reductions in availability of the analysed section

- Implementation of block-building mechanisms to harmonize & merge maintenance measures (especially regarding existing pavement management concepts => Cross-Asset Management)
- Intensive Software tests to evaluate/stabilize and optimize the implemented algorithms by means of using parts of an existing highway network reference project (see [1]) => Adaptation and calibration of the existing software prototype.

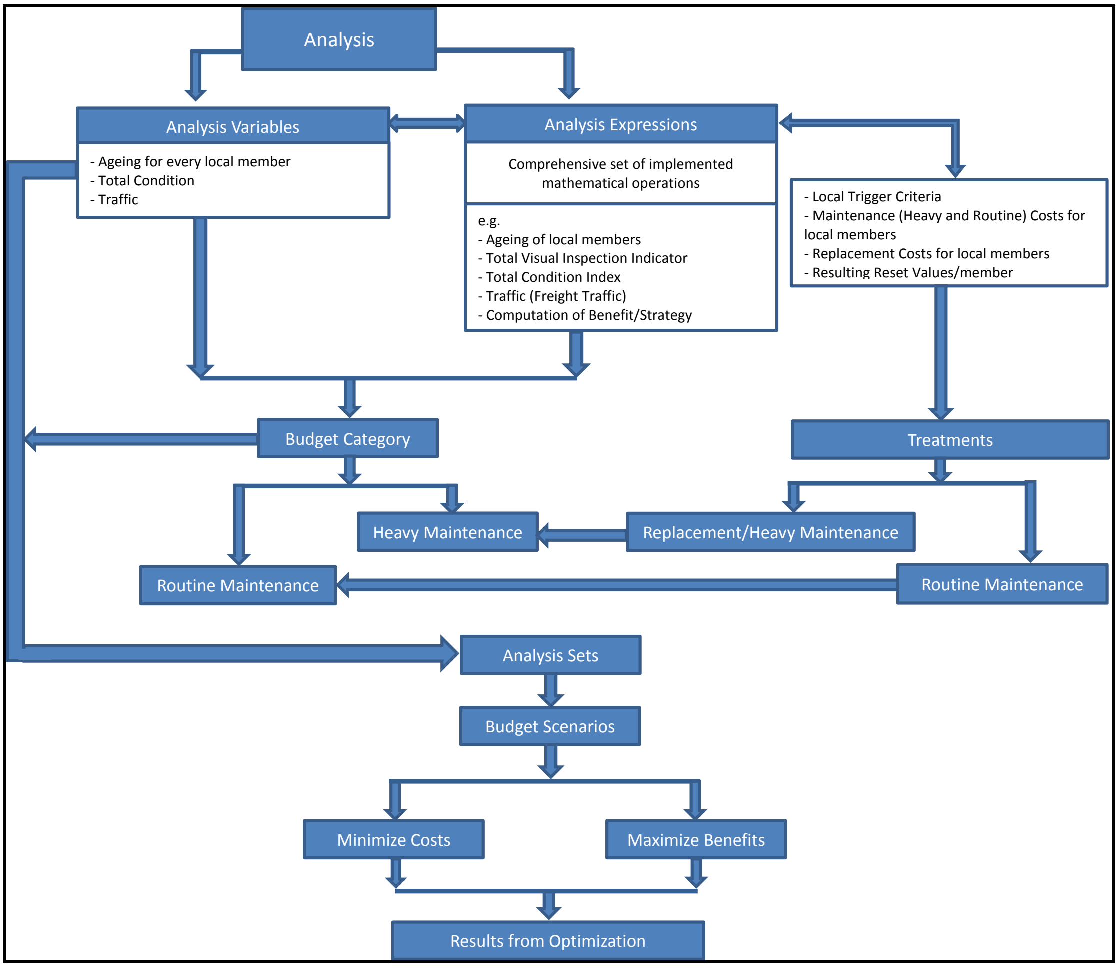

Fig. 3: Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA)

3.3 Reference-Analysis

After a detailed description of the input data and the data analysis the output (results and utilisation) is presented in the following. For that purpose a selected part from an existing reference project within the Austrian highway network (see [1]) was chosen to test and compare the previous results coming from the autonomous bridge and pavement management systems and cross-asset planning afterwards with the results of the newly developed integrated and optimized approach.

The following figures (Fig. 4 – Fig. 6) give an overview of the results for maintenance management of engineering structures – already adapted to the existing pavement management system. The figures represent the resulting progression of deterioration and condition of the analysed traffic junction and the corresponding costs of the optimized maintenance plans (comparing both optimised solutions - “minimize costs” and “maximize benefit”).

Fig. 4 shows the superposed global lifelines of the entire reference junction (all engineering structures included into the analysis) for both optimised solutions. During the progression of the analysed lifelines both routine maintenance interventions and the replacement of the structural member can be triggered and scheduled in the maintenance plan. In this process the inspection and maintenance history is considered as well as those time intervals when the structural members are appearing in the range of rating 3 (maintenance works) or in the range of rating 4 (retrofit, replacement). At the end of the process a weighted lifecycle curve for the whole structure is calculated. This global lifeline represents the superposition of all the individual curves - the relevance of the bridge element within the whole structure is reflected by its weighting.

Due to the fact that measures are not linked to a fixed date but are intended within a defined time period there is more than one possibility to schedule interventions for every single structural component. Thus, the aim of optimization is to find the most applicable combination of maintenance and replacement measures for all bridge elements taken from all the computed possible strategies. The optimal date of intervention and – in further consequence – the progression of the condition for every element within the analysis period of 30 years differs depending on whether the optimum is calculated concerning minimization of cost or maximization of benefit.

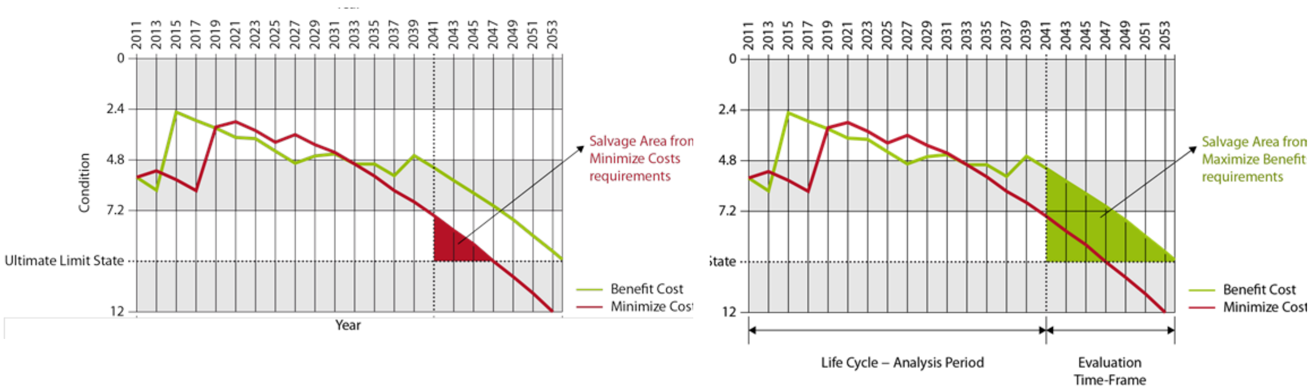

Fig. 4: Comparison of results – minimise costs versus maximise benefit

The distribution and the amount of costs for all structures within the analysis period of 30 years are illustrated in Fig. 5 (minimize cost) and Fig. 6 (maximize benefit). Especially in the last third of the analysis period more and cost-intensive maintenance measures are scheduled in the course of the optimum concerning maximize benefit.

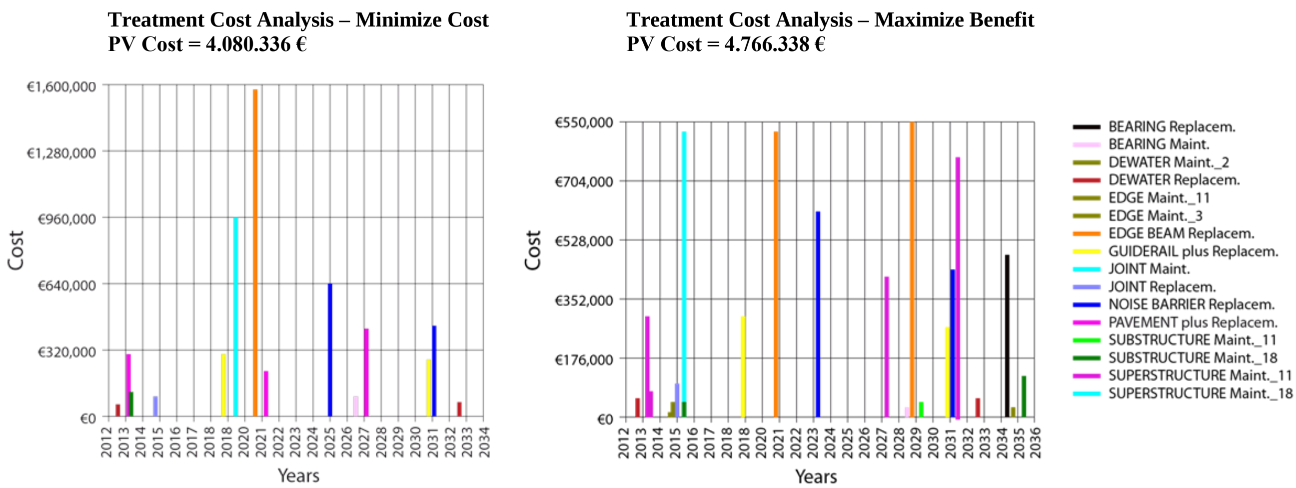

Fig 5: Total costs for the reference junction – minimize cost (left) and maximize benefit (right) optimisation

4. Conclusions

In the context with the aspired, integrated analysis and decision support tool for BMS (Bridge Management Systems) & PMS (Pavement Management Systems) the following milestones have been reached: At first procedures and methods for optimised, holistic maintenance planning for highway infrastructure were elaborated. Based on that, a computation tool for long-term life cycle prognosis (including cross-asset aspects) was developed and tested extensively by means of real data – provided by infrastructure owners. In the course of several reference projects, wishes and suggestions from clients were incorporated into the modeling procedures. Thus, the developed software-prototype represents a solution that was developed in close interaction with the real demands from the industry.

The advantages from the integrated approach are

- Mid-term & long-term maintenance & cost planning for freely chosen time frames
- Cross asset optimization
- Minimisation of costs under full compliance of load bearing capacity, serviceability and traffic safety
- Maximisation of availability
- Efficiency-comparison for different maintenance-strategies
- Comparison of LC–cost impact on different construction types
- Calculation of different scenarios: budget, traffic development, construction price development, assumed development on structural condition (categorisation)

4.1 Outlook

The present paper aims for an integrated approach for Life Cycle Cost analyses for road infrastructure. The current Asset Management procedures mainly focus on so called economic agency costs. These costs represent the owners/operators budgets, assigned to maintenance-related construction activities. In the course of generating the optimal maintenance strategy minimize-cost solutions are pursued, complying with the relevant safety and operability requirements.

For upcoming Bridge Management Systems the incorporation of the overall impact on national economy gets an increasingly demanded issue, as their monetary consequence is many times higher. The so called user-related time costs - that are given by reduced availability or non-availability of infrastructure due to construction works – are to be emphasized in this context (=> traffic jam or reduced construction site transit speed).

In addition environmental costs will be of huge strategic importance, as the optimization of this major external cost source will definitely be a highly demanded requirement for long term maintenance planning in future.

4.2 References

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