Future Oriented Lifecycle Approach on Bridges in Austria

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Abstract
Estimating the actual and future maintenance needs of bridges in a mountainous area is an essential task of the Austrian asset management process. At the moment, more than 5,000 bridges can be counted along the motorways and expressways, which define a total length of approx. 2,200 km of the federal road-network of Austria, which is owned and maintained by the state-owned motorway company ASFINAG. In 2014, ASFINAG decided to implement a future-oriented lifecycle approach, reviewing the situation of each bridge as a basis for short- to long-term maintenance planning. Former studies focused on network level performance prediction only, using the condition distribution of all bridge members as a basis for the forecast, but did not enable an assessment of single constructions. Based on a high number of inventory and inspection data but also on long-term experiences of the bridge engineers, it was possible to develop the necessary models for performance prediction (Markov chains) and bridge lifecycle modelling. Within a pilot project, the data of all bridges was implemented into the IMT (Infrastructure Management Tool, using asset management software system dTIMSTM) and analyzed using this new approach. Finally, the asset specific results from different scenarios were cumulated over the whole network for the estimation of the maintenance needs for 30 years. This paper presents both the modelling and implementation, but also the benefits and effects of having a future-oriented lifecycle approach available for an objective assessment of maintenance needs on bridges.

Keywords: Maintenance and Rehabilitation Strategies, Life Cycle Assessment, Life Cycle Cost Analysis, Bridge construction and management, Case studies
The Austrian motorway company ASFINAG

The ASFINAG Group is responsible for the planning, construction, operation, and toll collection of 2,183 km of motorways and expressways in Austria (see Figure 1). Since 1997, ASFINAG has had the “right of usufruct” to the motorway land, although this land still belongs to the Federal Government. This entitles ASFINAG to levy tolls and charges for use and access.

Figure 1: ASFINAG road network

Actual situation bridges

The diagram in Figure 2 shows the condition and age distribution of the bridges in the ASFINAG road network. 50% of bridges were built between 1971 and 1986.

Figure 2: Condition distribution of bridges in ASFINAG network related to age
Many of those structures are in fair to poor condition, so maintenance has to be carried out within the next few years.

**Objectives of the approach**

The main objective of the implementation of a new bridge management approach is the estimation of the actual and future maintenance needs of bridges on both the network level and the object level. Thus, ASFINAG decided to implement a future-oriented lifecycle approach, reviewing the situation of each bridge as a basis for short- to long-term maintenance planning. Former studies focused on network level performance prediction only, using the condition distribution of all bridge members as a basis for the forecast, but did not enable an assessment of single constructions. The new lifecycle approach, using Life Cycle Cost Analysis (LCCA), enables the bridge engineers to forecast the condition of each single bridge and to assess different heavy maintenance treatment strategies over 30 years. In addition, it is necessary to assess the effects and consequences of the 6-year Infrastructure Investment Program (IIP – net wide construction program) and to underline the necessity of investments for single structures. The practical application of this approach on all bridges of the ASFINAG network returns a high number of results, which can be summarized as follows:

- Estimation of monetary maintenance needs for the whole network, for sub-networks (regions), and for sensitive areas over a period of 30 years.
- Presentation of effects and consequences of the 6-year Infrastructure Investment Program (IIP).
- Development of condition distribution over 30 years.
- Estimation of the development of maintenance backlog on bridges over 30 years to see in which phase the efforts must be increased.
- Comparison of different heavy maintenance strategies for each single object and recommendation of optimum solution.
- Development of condition and recommendation for heavy maintenance treatments for each single bridge.
- Treatment cost and length distribution over 30 years.
ASFINAG decided to develop a simplified approach, which is easy to understand, supports existing lifecycle routines to the maximum possible extent, can be applied on all bridges of the network, and finally offers the highest possible benefit to all types of users. It should be an integrated part of the new IMT, which will be used to manage all kinds of structures built within the ASFINAG network.

The BMS as a part of the ASFINAG IMT

*Infrastructure Management Tool (IMT)*

In 2014 ASFINAG started to implement a holistic IMT to manage all types of assets, and provide a basis for the comprehensive asset management tasks. One of the decisive components of the IMT is a new Bridge Management System (BMS) for lifecycle cost analysis of all bridges (IMT-Bridges).

The implementation of the IMT is based on a stepwise procedure. A concept was written in 2014, followed by different pilot projects and pilot tests, where different solutions could be assessed and compared. Based on this experience, the IMT will offer different functionalities for different levels of users (management level, technical level, administrative level) to support the whole asset management process. For the storage of the data, two main databases will be used: the GIS database (ArcGIS™) as the basis for the definition of the network and the localisation and reference of all type of assets, and on the IMT database (dTIMS database) as the basis for the inventory, the condition information, and the lifecycle approach. The asset management tool dTIMSTM (Deighton Total Infrastructure Management System), of Canadian origin, which has already been in use for more than 18 years as a Pavement Management System, will be extended to manage all types of assets in the future. The first step was the extension of dTIMSTM for the bridges. In addition, other systems like Sharepoint™ (management cockpit), Doxis (document storage system), SAP™, and others will be incorporated into the IMT environment to support the different business processes.

*Bridge Management Tool (IMT Bridges)*

IMT Bridges was configured using dTIMSTM analytical asset management software, which enables the user to define the database structure, the database management procedures, and the analysis procedures according to the given models, algorithms, and requirements without changing the source code of the software. The data will be stored in an open SQL database that allows direct data access from external systems, which is
one of the key requirements for the IMT structure.
In the first step, a database structure was setup to transfer the necessary bridge data from the existing bridge database BAUT into IMT Bridges, and to prepare the data for LCCA. This task was performed using dTIMSTM database management functionality as shown in Figure 3. After implementing the data of all ASFINAG bridges, the models were incorporated into the system and the LCCA procedure was setup.

![Figure 3. Data management module IMT Bridges (dTIMSTM)](image)

**Modelling lifecycle approach for bridges**

**Life Cycle Cost Analysis (LCCA)**

As already mentioned, a main objective for the selected approach was the implementation of a solution, which enables the bridge engineers to see the future development of the bridge performance on each single bridge and to compare different heavy maintenance treatment strategies over a 30-year period. The technical and monetary effects of the different maintenance activities define different lifecycle solutions and enable a comparison of costs and benefits as a basis for different types of mathematical optimization (minimize cost optimization, maximize cost-benefit ratio optimization, and so on). The development of the different models and components for this comprehensive LCCA was a decisive factor for the whole project and included:
• Development and implementation of a new total structural condition index, which will be composed from the condition information of the different bridge components.

• Development and implementation of a stochastic performance prediction model using the new total structural index.

• Development and implementation of a heavy maintenance treatment catalogue.

• Development and implementation of cost-benefit analysis and optimization procedures.

• Implementation of the new algorithm and models into IMT Bridges.

The modelling focused on a general approach, which can be applied on all bridges, and takes into account the actual data availability.

**New structural condition index for bridges**

As in many European countries, the condition of the bridges will be collected by monitoring the different components of a bridge (superstructure, bearings, edge beam, expansion joints, sub-structure, and so on) on a given interval using the component rating scores (1 = very good to 5 = not acceptable, according to the Austrian standard RVS 13.03.11 (FSV, 2011)). In addition, a total condition index will be used as a general assessment parameter, but this will not be calculated out of component rating scores. Therefore, to apply a simplified and understandable algorithm, ASFINAG decided to carry out the performance prediction on the object level and not on the component level, taking into account general heavy maintenance treatments only. Thus, it was necessary to develop a new structural condition index for bridges SCI under the following requirements:

• Consideration of component rating score.

• Consideration of importance of the different components.

• Derivation of a condition distribution from the new structural index as input vector for the probabilistic performance prediction using Markov chains.

To fulfil these requirements, a special task group developed the new SCI, which is mainly influenced by the condition of the superstructure. The condition of other components either increases or decreases the value of the index according to the importance of each bridge component. The following equations show the calculation procedure of this new structural index:
• Calculation of the weighted (maximum) structural condition index SCI* as a sum of the weighted component rating scores and the superstructure rating score:

\[
SCI^* = RS_{\text{superstr}} + \sum \frac{W_i}{10} \left( R_{S_i} - R_{S_{\text{superstr}}} \right) \quad \text{for all } R_{S_i} > R_{S_{\text{superstr}}} 
\]

(1)

• Selection of the highest component rating scores except superstructure, pavement, and equipment:

\[
R_{S_{i,\text{max}}} = \max(R_{S_i}) 
\]

(2)

• Consideration of better condition of components in comparison to condition of superstructure:

\[
SCI = SCI^* - \frac{R_{S_{\text{superstr}}} - R_{S_{i,\text{max}}}}{10} \quad \text{for } R_{S_{i,\text{max}}} < R_{S_{\text{superstr}}} 
\]

(3)

SCI* ............ Weighted structural condition index (maximum value)
RS_{\text{superstr}} ........ Rating score superstructure
RS_{i} ............. Rating score bridge component i (substructure, bearing, expansion joint, drainage and isolation, edge beam)
W_i ............... Weighting factor of bridge component i (substructure = 1, bearing = 1; expansion joint = 1, drainage and isolation = 2, edge beam = 2)

The new structure condition index SCI returns a value between 1 and 5 and will be transformed into a 5 term vector, where each single term represents the percentage of a condition class (related to the rating score from 1 to 5). To convert SCI into a maximum of two condition classes, the following equations will be used:

• Calculation of percentage \( P_{R_{S_{i,\text{max}}}} \) for condition class of \( R_{S_{i,\text{max}}} \)

\[
P_{R_{S_{i,\text{max}}}} = \frac{SCI - R_{S_{\text{superstr}}}}{R_{S_{i,\text{max}}} - R_{S_{\text{superstr}}}} \quad \text{for } R_{S_{i,\text{max}}} \neq R_{S_{\text{superstr}}} 
\]

\[
P_{R_{S_{i,\text{max}}}} = \begin{cases} 0 & \text{for } R_{S_{i,\text{max}}} = R_{S_{\text{superstr}}} \\ 1 - P_{R_{S_{i,\text{max}}}} & \text{otherwise} \end{cases}
\]

(4)

(5)

• Calculation of percentage \( P_{R_{S_{\text{superstr}}}} \) for condition class of \( R_{S_{\text{superstr}}} \)

\[
P_{R_{S_{\text{superstr}}}} = 1 - P_{R_{S_{i,\text{max}}}} 
\]

(6)

The practical testing of this procedure is still going on and will return some improvements and extensions within the upcoming months.

**Performance prediction**

Based on a high number of inventory and inspection data, but also on long-term
experiences of the bridge engineers, it was also possible to develop the necessary models for performance prediction. The same task group decided to use a probabilistic model in form of Markov chains, which enables a general performance prediction of each single bridge using the input vector of the new structural condition index. The transition probabilities for the models could be derived from the inspection data and were compared for different types of bridges. Because of the small differences between the different types of bridges, it was decided to use a general model as a first approach and intensify the investigations for special structures in the future. The model can be seen in the following equation:

\[
\text{SCI}_{t=n} = T^n \cdot \text{SCI}_{t=0} \quad \text{with} \quad T = \begin{pmatrix}
0,845 & 0,152 & 0,003 & 0 & 0 \\
0 & 0,919 & 0,08 & 0,001 & 0 \\
0 & 0 & 0,92 & 0,08 & 0 \\
0 & 0 & 0 & 0,92 & 0,08 \\
0 & 0 & 0 & 0 & 1
\end{pmatrix}
\]

(7)

Although only one model will be used for performance prediction, the bridge engineers returned a positive feedback after the assessment and judgment of the first results.

**Heavy maintenance treatment catalogue**

With regard to the new structural condition index SCI, the main bridge component for the definition of the heavy maintenance treatments is the superstructure. Furthermore, ASFINAG decided to exclude smaller maintenance activities (for example, repairing of equipment, and exchange of single expansion joints and bearings) from the lifecycle approach because of difficulties in predicting these activities, having a general performance prediction model only, and covering the costs for this treatment within a separate budget. At the moment, the treatment catalogue defines 3 main groups of treatments, which are based on the experience of the Austrian bridge lifecycle:

- **I1** – Heavy maintenance treatment 1 (repair of main components, age of bridge < 40 years)
- **I2** – Heavy maintenance treatment 2 (reconstruction, replacement of components, age of bridge ≥ 40 years and < 60 years)
- **NB** – New construction (replacement of major components, age of bridge ≥ 60 years)

Besides the listed triggers, the treatment catalogue includes a calculation procedure for
the costs and the different effects on the SCI (reset vectors).

**Practical implementation**

Based on the object-level LCCA, the asset specific results from different scenarios were cumulated over the whole network for the estimation of the maintenance needs over 30 years (Figure 4). The resulting condition distribution is shown in Figure 5.

The basic scenario for the assessment of the maintenance needs is a minimize cost analysis, which aims at having no bridge in condition class 5 according to the Austrian
Results and outlook
Based on the results of the first analysis, an estimation of the future maintenance budget could be carried out (see Figure 6) and compared with already existing estimations of general network level approaches. An increase of the budget for new construction could be seen from medium to long term and will strongly influence the Infrastructure Investment Program (IIP).

Based on the existing results, the system will be improved within the next month to increase the accuracy of the models and the efficiency of the selected approach. The practical application of LCCA on the Austrian bridges showed a high potential for a future-oriented solution, which fulfils the given requirements and enables the ASFINAG to underline the necessity of future investments on an objective basis.

References