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Integrated Lifecycle Assessment in Railway Infrastructures

127 - Life-Cycle-Engineering im Konstruktiven Ingenieurbau Und Hochbau

Abstract

Railway operators are in a continuous pressure to minimize the escalating maintenance and rehabilitation costs of infrastructures; at the same time they are expected to provide a safe and reliable service. This contribution attempts to illustrate an integrated approach for maintenance of existing railway track network by optimum allocation of natural and economical resources. Integrated lifecycle assessment methodology was used for the study and several lifecycle assessment models have been developed. The procedural action is development of LCA models for railway components in the railway network, eventually be combined to assess the lifecycle of the entire network. Stochastic numerical analysis supported the study of different degradation scenarios and enabled to incorporate uncertainties.

Keywords:

Lifecycle performance, railway bridges, railway tracks, deterioration models, rail network performance

1. Introduction

The railway sector nowadays is increasing the number of high speed lines as well as demanding cars with higher axle loads due to the increasing amount of bulk transport of goods in long distances (Olofsson et al, 2005; SB – LRA, 2007): at the same time there is a growing standard and demand for safety in business and society. In this regard, infrastructure facilities are expected to be economically efficient in serving a specific purpose, and, at the same time should fulfill the given requirements concerning safety. In consequence, the need to focus on risk-informed, optimized decision is immense. With the aid of lifecycle risk assessment, different decision alternatives can be compared and ranked.

Railway infrastructures such as railway bridges and tracks are long-lived assets whose life spans stretch 30 to 100 years. The performance of a railway infrastructures depends on, (i) a reliable design; (ii) optimal maintenance strategies supported by inspection monitoring methods (iii) reliable performance assessment approaches, (iv) suitable prediction techniques (Lichtberger, 2007; Quiroga, 2012). Therefore, railway operators continuously endeavor to apply artificial intelligence-based maintenance planning methods. These maintenance planning methods are dependent on numerous factors, track degradation model being among them (Quiroga, 2012). Maintenance planning algorithms (Koza, 1992) based on degradation models and stochastic variables were performed by (Michalewicz/Fogel, 2002; Lake/Ferreira, 2002). [sentence structure not clear here]. On the other hand, a stochastic lifecycle performance assessment of existing railway bridges supported by numerical simulations, investigated the factors considerably contributing [?] to aging of bridges (Strauss et al, 2015).

Along with the performance assessment based on degradation modeling [incomplete sentence]: studies on the lifecycle costs of railway components provided information for cost-effective decision by balancing performance requirements (Veit, 2013, Patra et al, 2008) and comprehensive lifecycle assessment approaches of bridges studied by Guangli ,2012; Grossberger, 2014; Strauss et al, 2015; Klatter et al, 2006.

However, those lifecycle assessments and applied models and techniques so far incorporate in most cases either only the lifecycle cost or the lifecycle performance of structures.However, it is highly recommended to incorporate the societal and environmental requirements, which means that the lifecycle cost analysis in most cases considers only the economic aspect. Furthermore, the lifecycle performance and the related LCC analysis in infrastructure consider structural system and railway components in a separate manner. This study has been undertaken to analyze railway infrastructures in an integrated manner.

2. System analysis

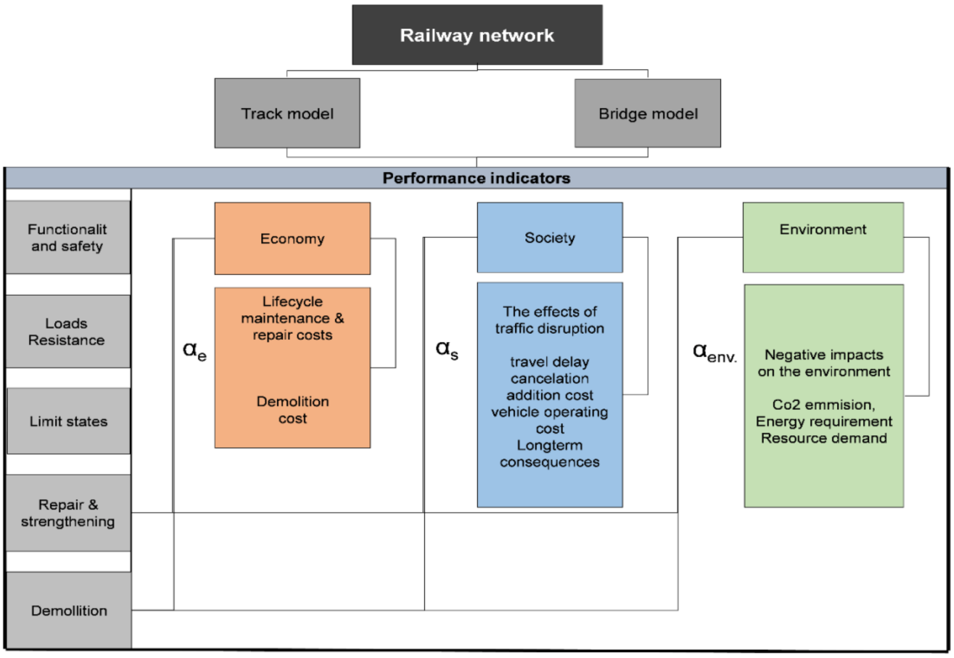
2.1 Railway tracks and bridges

In the railway sector, the technical lifetime performance of infrastructures such as bridges and railway tracks should be kept above the threshold level in order to fulfill the societal demands. These demands are expressed by **R**eliability, **A**vailability, **M**aintainability and **S**erviceability (RAMS) of the railway network. RAMS based European standard documents EN 50126 (CENELEC, 1999) for railway infrastructure do not consider the social and environmental criteria. These issues are governed by national regulation and legislation and are not included in EN 50126. However, to establish an open communication with the public and politics about the RAMS/LCC efforts are [?] needed to meet the functional user requirements (Klatter et al, 2006).

The safety levels of bridges decreases continuously as a result of deterioration processes caused by environment-induced, mechanical and chemical loads. In addition, there are uncertainties inherent to engineering structural systems because of material properties, loading conditions, model imperfections, and variability of the environment as well as uncertainties related to designers and/or code writers. In Austria, a condition index is mostly expressed in condition classes of 1 to 5 in which class 1 is assigned to bridges with very good condition while class 5 bridges are prohibited to be in service. This condition index is determined by visual inspections. The other method to describe the safety level of bridges is the reliability index β. With the help of time-dependent reliability index β, it is possible to divide the operational and structural measures into two categories. These categories include actions which slow down or accelerate the deterioration of the condition and/or the load carrying capacity of the bridges. If the actual level of reliability of a bridge can be determined by the given innovative methods, the further change in β factor because of a given strengthening measure can be observed. This can make the infrastructure management in long-term planning considerably easier.

2.2 Integrated assessment approach: railway tracks and bridges

This is a procedural approach for preparating the basis for the lifecycle optimization based on the lifecycle performance and the direct and indirect consequences. The goal of the project is to integrate lifecycle assessment approach models a rail network with a cut-off criterion of assessing existing rail network by considering the technical and sustainability requirements. The approach enables to develop a database for which where several general railway component models have been developed. This includes the full-probabilistic bridge performance analysis, rail track, rail track foundation models and rail track in tunnel. The component models are individually treated and can be integrated to form a large model of an entire railway network. This approach illustrates the lifecycle method to be applicable either for individual model or a combined assessment to make a prognosis and maintenance decision based on for an integrated manner. Furthermore, the performance indicators related to the technical requirements and sustainability criteria are normalized and the model will provide options to apply weighting factors to each criterion depending on the local and regional time dependent priorities. The total performance can be computed by multiplying the normalized performance indicators of the economic, social and environmental requirement by the corresponding weighting factors. Figure 1 illustrates the framework of the analysis procedure and the contents to be established in the database.



α_e, α_s, α_{env} are weighting factors for the economic, social and environmental performance criteria depending on the local and regional priorities

Figure 1: Integrated lifecycle cycle assessment of existing railway network

3. Application examples

For the application of the prescribed approaches, lifecycle models were developed to calculate and analyze the railway system. In this case the focus was to study the practical interpretability of the proposed integrated assessment approaches by examples. It is important to note that different operations and system relation require individually tailored models depending on specific regional and local conditions. The sub-models treated in the study are the following:

- Rail track foundation model
- Rail track model
- Rail track in tunnel model
- Railway bridge models

In addition, factors which determine content and discontent of passengers related to maintenance actions which will have long-term effect on the attractiveness of the railway network are identified. The basic factors like punctuality, availability, operation times, safety, information and reachability determine the dissatisfaction of the passengers. The quality of public transport increases with the fulfillment of the basic to excitement factors for example right-time information about delay, connections, connections to other means of transport etc. (VCÖ, 2014).

3.1 Rail bridge model

In the bridge model, the performance of the railway bridge Krems-Grein in Lower Austria was analyzed for serviceability (SLS) and safety (ULS) levels in a full-probabilistic method. For a realistic simulation of the system, software ATENA was implemented. Combined with the Monte Carlo Simulation the analysis enabled the evaluation of the reliability indexes of individual structural components as well as of the whole structure.

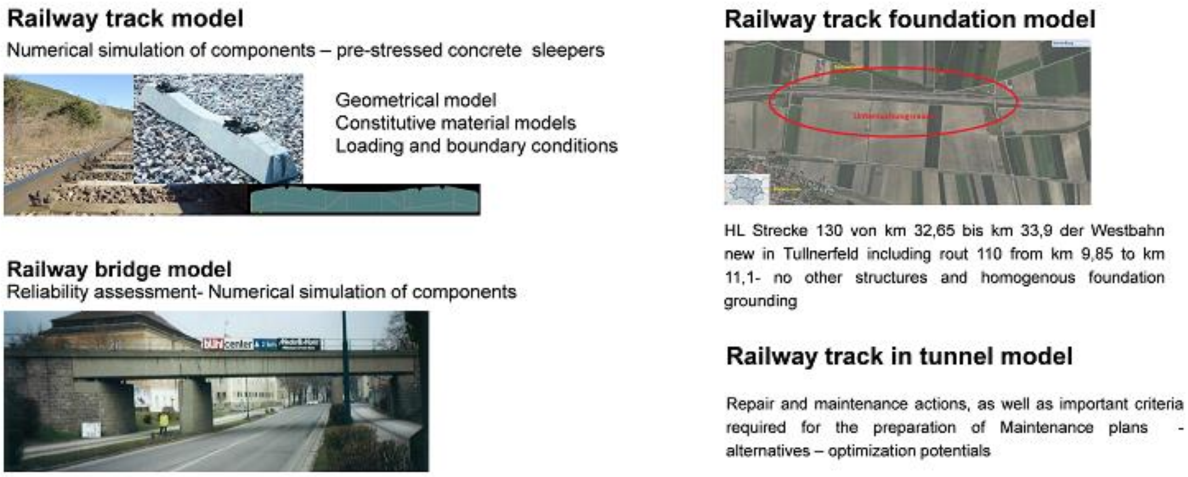


Figure 2: Sub-Models for an integrated analysis

The numerical simulation facilitated modeling the geometry and material response in detail and assisted in studying the stresses and the separate proof of resistance through the analysis of cross-sections. In modeling the ballast bed, a Drucker-Prager material model was used. Structural responses: displacement, stress and strain are monitored at macro elements of section length 1 m interval on the top, the bottom and middle depth of the superstructure. The sections divided into macro-elements serve to incorporate future inspection results and reanalysis of the bridge performance at any service life of the bridge. From the monitoring, structural responses such as (a) Stress tensors σi = [σxx, σyy, σzz, σxy, σxz, σxy], (b) Strain tensors εi = [εxx, εyy, εzz, εxy, εxz, εxy], and (c) displacement tensors ui = [ux, uy, uz] were extracted. The continuous load application coupled with the evaluation of structural behavior in reference to the serviceability (a) SLS frequent serviceability load combinations, $ß_{fre\_f}$, (b) SLS Characteristic serviceability load combinations, $ß_{cha\_c}$, where the reliability indexes are found to be 3.0 and 3.7 respectively.

The following figure shows the deterministic and stochastic analysis results of stresses

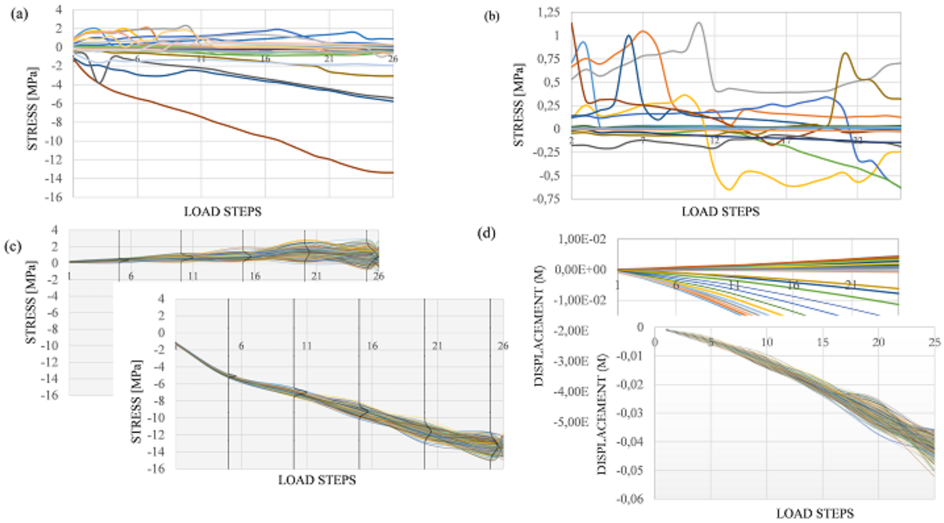


Figure 3: Results of the numerical analysis (a) stress σ_{xx} at all monitoring points (Top & Bottom) - deterministic, (b) stress σ_{xx} at all monitoring points (middle) – deterministic, (c) stochastic max and min stresses σ_{xx}, (d) displacements: deterministic & stochastic

3.2 Rail track foundation model

The railway track foundation which is observed for this study is a part of the *Westbahn* and the *Tullnerfeldbahn* in the area Tullnerfeld (Lower Austria). In this section both railways are on the same roadbed. For the LCA in this model, the database incorporates input material which was required to complete the railway track foundation over a length of 1.25km.

3.3 Rail track model

In the rail track model, pre-stressed concrete sleepers, rails and fastenings have been considered. Numerical simulations are performed on pre-stressed concrete sleepers using ATENA and the results are incorporated to ILCA database. The simulations were performed for the pre-stressed sleepers produced by MABA company , Austria together with the Austrian federal railways. The pre-stressed considered are type L1 and L2 which are used in branch and main lines of Austrian railways respectively. The simulation considered the geometrical model, constitute material models and loading boundary conditions. The Numerical Simulation incorporated in the database is used to assess and predict the crack distribution, stresses for serviceability limit sate (SLS) and fatigue.

3.4 Rail track in tunnel

Maintenance actions in tunnel systems, which are influenced by the design and construction of a tunnel are identified. For tunnel railway tracks, the maintenance concept is prepared during the design stage of the tunnel. With this regard, the preparation processes of the maintenance concept and related essential steps are sketched. This supports the optimum lifecycle maintenance planning approach by including the LCC and sustainability criteria.

4. Conclusion

Within the project ILCA (exploratory project) it has been possible to develop a database and design several Lifecycle analysis models of the railway system. The component models can then be integrated to form an entire railway network. In the models material parameters, geometry, loads model inaccuracies were accounted by stochastic methods. The construction materials and maintenance actions during the whole life span of the models were extracted. These are linked to passenger demand and contribute to infrastructure management to optimize the LCP and sustainability performance factors.

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