DEVELOPMENT OF A SYSTEMATIC APPROACH FOR EVALUATION OF THE CONDITION OF THE TUNNEL EQUIPMENT

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ABSTRACT

Road tunnels play a central role in ensuring the efficiency of the road transport network. Maintaining their availability and safety is therefore of great importance. To ensure this, the condition of the structures must be regularly recorded, documented and evaluated.

The structural inspection of road tunnels in the federal trunk road network in Germany is carried out according to a systematised procedure in accordance with DIN 1076, although the focus is primarily on the structural condition assessment. The question of the condition of the operational and safety-related tunnel equipment remains largely unanswered. This is recorded and summarised via regular maintenance and inspection. To date, it has not been summarised, e.g. by means of a condition mark as for the structure. In Austria, an evaluation methodology for operational equipment already exists, but it is to be updated based on experience gained from its application.

As part of a research project by the Federal Highway and Transport Research Institute, a system for assessing the condition of operational and safety equipment has therefore been developed. This provides a basis for forecasting the availability and necessary maintenance measures for the tunnel equipment in Germany and will thus be available in future as additional information alongside the condition rating for the structure.

For this purpose, practical evaluation criteria and an evaluation methodology were developed, and weighting approaches for the various equipment components were studied to take into account their relevance to tunnel safety. In addition, further parameters were defined to consider the importance of the tunnel in the road network for prioritization of measures.

This article presents the results of the study and highlights the challenges involved in developing and applying the system, the findings of the evaluation of the system on a specific structure, and the steps required to further refine the system for application.

Keywords: Condition mark, tunnel equipment, assessment method.

1. INTRODUCTION

The operational and safety equipment of road tunnels plays a central role in the availability and safety of the road transport network. While there is an established procedure for assessing the structural condition of tunnels in Germany in the form of DIN 1076 [1], there has been no comparable structured methodology for assessing tunnel equipment condition to date. The preparation of maintenance requirement forecasts is therefore based on the condition

assessment of the tunnel structure – the extensive renewal requirements for tunnel equipment have not been considered to date. Due to the scope of a tunnel's operational equipment, an underestimation of the maintenance costs for tunnel equipment and its cyclical renewal requirements can potentially lead to an incorrect underestimation of the follow-up costs [2].

The aim of the research project presented here [3] was therefore to develop an objective, comprehensible system for assessing the condition and predicting the availability of operational and safety-related tunnel equipment. The result is to be made available as additional information alongside the condition rating for the structure. This provides operators with a basis for deriving maintenance measures and strategies that better reflect the future funding requirements for maintenance demand forecasting.

The project was awarded to a consortium consisting of ILF and ASFINAG. ASFINAG's interest was mainly based on the fact that they had already been using a similar system for several years, but this system had weaknesses in the objectivity and systematics of the assessment areas, and participating in this project offered them the opportunity to update and further develop their methodology in accordance with RVS [4].

2. STRUCTURE OF THE TUNNEL EQUIPMENT

A structured classification of tunnel equipment is essential for systematic condition assessment and differentiated analysis of technical equipment. This two-stage classification is based on the specifications of RE-ING [5] and was further developed specifically during the course of the project. The aim was to create a uniform yet adaptable structure that both ensures comparability between different tunnel systems and considers the individual characteristics of road tunnels.

The functional blocks according to RE-ING Part 3 Section 3 provide a basic structure. Based on this, the functional blocks are subdivided according to the associated trades. The functional blocks represent higher-level operational functions such as lighting, ventilation or communication, while the trades, as the next smallest evaluation units, represent specific technical systems such as jet fans, emergency call systems or luminance measurements.

Table 1 shows the structure of tunnel equipment using the example of the ‘ventilation system’ functional block.

Table 1: Structuring the tunnel equipment into functional blocks and trades using the example ‘ventilation system’

functional block	trade
ventilation	Flow velocity measurement
	Jet fans
	Ventilation control
	Vibration measuring instruments
	Axial fans
	Ventilation flaps
	Ventilation of escape routes
	Fog measurement
	Wind measurement

The trade list usually contains around 80 trades and provides a good starting point for the majority of German road tunnels. Due to the individual nature of tunnels, minor adjustments may be necessary in practice. In addition, the assessment methodology always offers the

option of subdividing the trade list into even finer granularity if necessary (e.g. at the level of components or parts).
This approach enables a differentiated condition assessment at the functional level. At the same time, a flexible framework was deliberately created in the project in order to be able to map tunnel-specific equipment variants.

3. EVALUATION CRITERIA FOR TRADES

The core of the assessment methodology consists of five key assessment criteria, which are used to enable a differentiated and objective assessment of the technical condition of the individual trades. These criteria were defined based on literature research, expert interviews and practical experience and form the basis for determining the condition rating. Each criterion highlights a specific aspect of the performance of technical systems in tunnel operation. The five assessment criteria are defined as follows:

- The **functional condition** describes the ability of a component to reliably fulfil its intended function in tunnel operation. This assessment is based on functional tests, operational observations and, where applicable, measured values.
- The **substantial condition** assesses the physical condition of the components. This includes aspects such as corrosion, material fatigue, mechanical damage or electrical defects. The assessment is usually carried out visually or by means of simple measurement procedures as part of maintenance and inspection.
- The **susceptibility** of a component to failure is assessed based on historical failure data or empirical values. Both the frequency and the effects of failures are considered, thus allowing conclusions to be drawn about the reliability of a component.
- **Spare parts availability** describes whether sufficient spare parts are available or can be procured for a component. It considers both stock levels and the delivery capacity of manufacturers or suppliers.
- Finally, **support availability** assesses whether the necessary technical expertise is available to operate and maintain the trade throughout its life cycle. This includes both internal expertise and external support from manufacturers or service providers. For IT and software-based systems, the availability of updates and security patches is also considered.

For the practical application of this assessment logic, a structured assessment sheet was developed in the project, which serves as a central tool for carrying out the condition assessment (see Figure 1).

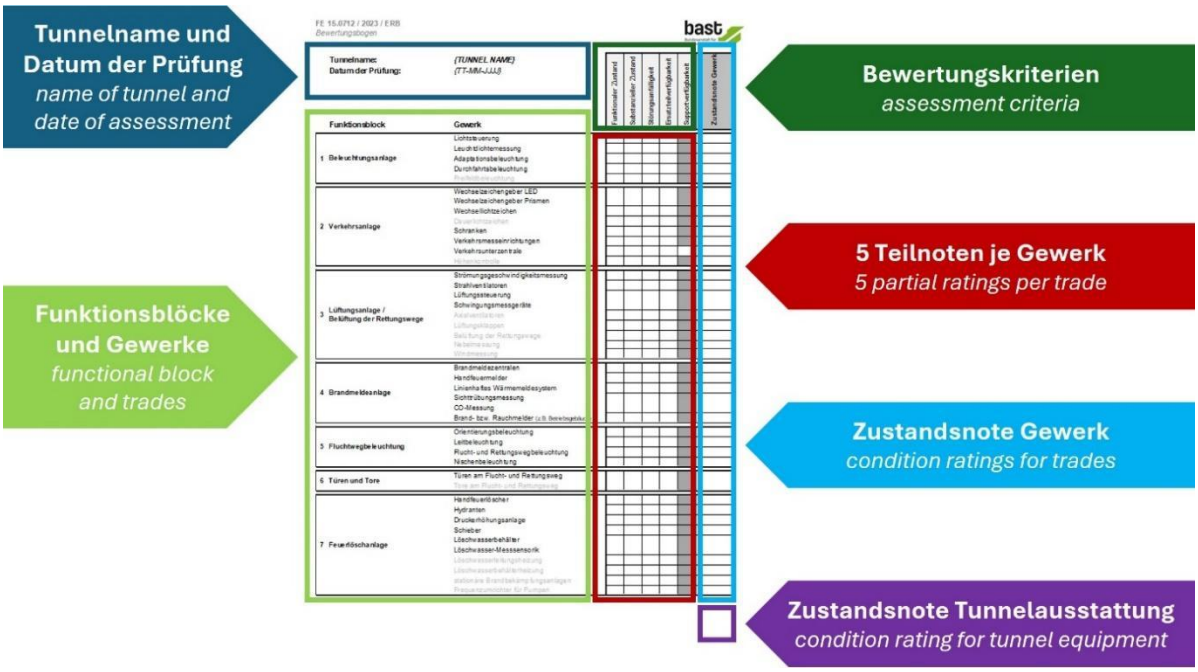

Figure 1: Overview of the contents of the evaluation form

The evaluation sheet is structured as an MS Excel file and contains a tabular overview of all functional blocks and the associated trades. For each trade, the five sub-scores for the evaluation criteria must be entered during the evaluation. The ‘condition score for trades’ and the ‘condition score for tunnel equipment’ are calculated automatically using predefined aggregation methods. In addition to the overview sheet, the evaluation form contains a template for an explanatory sheet that provides space for photographic documentation and textual comments. This increases the traceability of the evaluation and supports quality assurance.

4. GRADING OF THE EVALUATION CRITERIA

As part of the assessment methodology developed, a uniform five-point grading scale was introduced. The scale ranges from grade 1 (‘very good’) to grade 5 (‘poor’) and allows for a differentiated yet intuitive assessment of the condition of technical tunnel equipment. The choice of an odd-numbered scale with a neutral middle grade was made deliberately to enable a balanced assessment without having to force a positive or negative bias. A sixth level, as provided for in DIN 1076 with grade 6 (‘unsatisfactory’), was not adopted, as such a poor condition in the area of tunnel equipment would usually be accompanied by an immediate suspension of operations and is therefore outside the scope of the methodology.

A specific grading system was developed for each of the five evaluation criteria. These grading systems consist of clearly defined descriptions for each sub-grade level and specific control questions that assist the user in evaluating the individual criteria. The control questions are formulated in such a way as to allow for the most objective and comprehensible classification possible. Depending on the criterion, logical links such as AND or OR conditions are used to adequately reflect the complexity of technical relationships. Where possible, the grading systems have been supplemented with practical examples.

Figure 2 shows a schematic representation of a rating system with control questions using the example of the evaluation criterion ‘functional condition’.

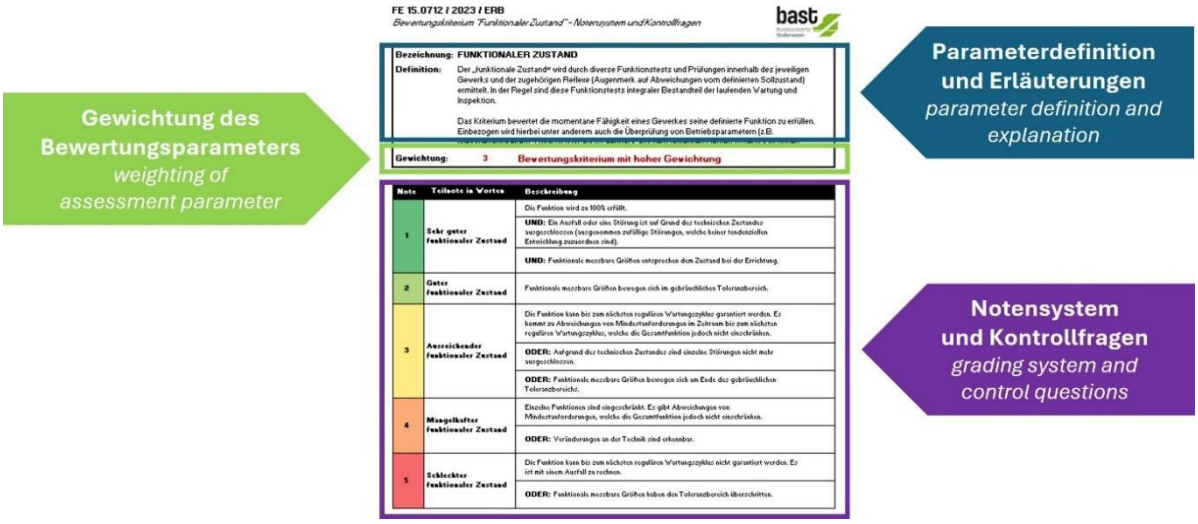

Figure 2: Presentation of the contents of the 'grading system with control questions' using the example of the assessment criterion 'functional condition' in the evaluation form

The five grading systems are an integral part of the evaluation sheet, which serves as a central tool for applying the methodology. In addition to the overview sheet for evaluating all trades (see Figure 1), the evaluation sheet for each evaluation criterion also includes the corresponding grading system with control questions for each sub-grade.

5. AGGREGATION OF CONDITION GRADES

Another important element of the assessment methodology is the aggregation of condition ratings, which is carried out both at the level of individual trades and for the entire tunnel equipment. This process is shown schematically in Figure 3.

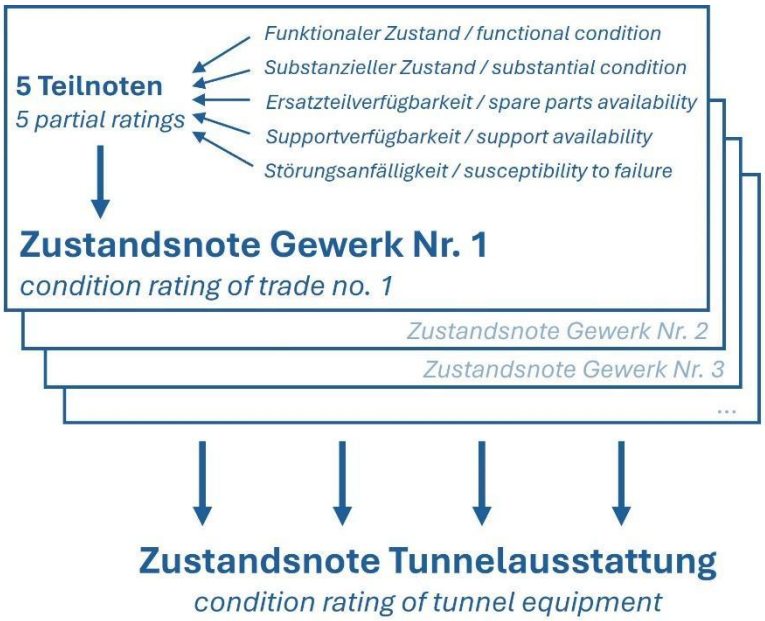

Figure 3: Schematic representation of the aggregation of the different condition marks

For each trade, a condition score is first calculated – the so-called ‘trade condition score’ – which combines the five evaluation criteria mentioned above. For this purpose, weightings for the individual criteria were determined in an expert workshop to reflect their respective relevance for safe and reliable tunnel operation. The functional condition is given the highest

weighting (3), followed by the substantial condition, susceptibility to failure and spare parts availability (2), while support availability is given the lowest weighting (1).

The weighted aggregation of these five evaluation criteria already results in a condensed, objective score after this step, which can be used both for short-term action planning and for strategic maintenance management. In practice, the ‘condition rate’ allows for the targeted prioritisation of maintenance and renewal measures, especially for components with a critical impact on operational safety. It can be used as a basis for decisions on adjusting maintenance intervals, planning replacement investments or initiating refurbishment measures.

In addition, the ‘condition rating for trades’ provides the basis for the overall assessment of the entire tunnel equipment and its consolidation into the so-called ‘condition rating for tunnel equipment’. Various methods were examined in the project for this aggregation, including simple averaging, weighted averages by functional blocks, and methods based on maximum values or median sets. The aim was to find a method that considers both the technical relevance of individual components and the heterogeneity of the tunnel facilities.

The ‘condition rating for tunnel equipment’ is available as an additional optional condition mark for road tunnels. It serves, for example, as an integral part of the overall assessment of tunnel equipment and can be used in aggregated form to derive long-term trends or to compare different tunnel facilities. In addition, it can serve as an indicator for budgeting in the context of resource requirement planning or to support transparent communication with supervisory authorities and internal stakeholders.

6. PRACTICAL APPLICATION

The assessment methodology developed in the project was specifically designed for practical application in operational practice and validated using a real German road tunnel. Particular emphasis was placed on ensuring that the methodology was not only theoretically sound, but also operationally feasible. The methodology was applied in collaboration with experts from tunnel operations, which provided practical feedback on the comprehensibility, manageability and informative value of the assessment logic. This feedback was directly incorporated into the optimisation of the methodology and led to a noticeable improvement in its practical applicability.

To facilitate practical application, a structured evaluation form has been developed as an MS Excel file, which will be available in future and will enable the evaluation of individual trades based on defined criteria and control questions.

The methodology was designed to be flexible and adaptable to different tunnel types and operator structures, thus enabling broad applicability and acceptance in the German federal highway network.

7. SUMMARY, CONCLUSION AND OUTLOOK

The project presented here makes a fundamental contribution to optimising the maintenance management of road tunnels by providing a structured and objectifiable methodology for recording and evaluating the condition of operational and safety-related tunnel equipment. While an established procedure exists for the structural substance in the form of DIN 1076, there has been no comparable approach for technical equipment to date, even though this contributes significantly to the availability and safety of tunnel facilities. The methodology developed is based on a clear structure of functional blocks and trades, a five-stage assessment logic with specific criteria, and a comprehensible aggregation of results. Validation in a real tunnel confirmed the practicability and relevance of the system but also showed that further

evaluations of additional structures are necessary with regard to the assessment scheme. This further development is necessary in order to test and apply the assessment system with different criteria (e.g. traffic type, lengths, level of equipment) and with regard to its robustness under different technical and organisational conditions. In particular, the aggregation methods for determining the overall condition assessment should be further validated and, if necessary, adapted.

In the long term, the plan is to provide a methodology at federal level that offers a uniform assessment basis for all tunnel facilities in the German federal highway network. In Austria, the results of the study will be used to improve the existing integrated asset management tools.

The results of the project provide a solid basis for maintenance planning decisions by enabling a more accurate representation of future funding requirements for maintenance demand forecasting and providing an improved planning basis for maintenance measures. In addition, the results make an important contribution to the digitalisation of transport infrastructure by digitally mapping the condition assessment process in a first step, thus laying the foundations for a digital way of working.

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