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Comparing Roadway and Railway Bridge Maintenance: Performance Indicators, Predictive Models and Path to Digitalization

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Roadway and railway bridges have different inspection procedures, performance indicators, maintenance strategies and decision processes. This paper compares two methodologies, an inspection and management system for roadway bridges implemented in a Portuguese municipality, and a predictive approach to forecast the degradation in railway systems based on geometric and structural indicators. The comparison identifies the main differences in condition evaluation criteria, indicators and data availability, while highlighting aspects in which both approaches can complement each other to support more consistent assessments.
This paper also discusses how inspection data and performance indicators can contribute to risk-aware and reliability-oriented maintenance decisions, particularly when models are capable of being updated as new data becomes available. The differences in availability and source of information between the two assets will also be analyzed. Although the two infrastructures follow distinct operational and inspection contexts, the comparison shows that both can benefit from clearer indicator structures and more systematic use of predictive information.
Based on these insights, the paper outlines how structured data flows and models that can be update may create conditions for future digitalization efforts, including workflow improvements that may support the later development of a Digital Twin. The results provide a realistic and technically grounded step toward more informed maintenance strategies for roadway and railway bridges.

Keywords: Roadway bridges; Railway bridges; Performance indicators; Maintenance management; Risk-based prioritization; Reliability; Digitalization.

1. Introduction

Roadway and railway bridges are essential components of transportation networks whose condition deteriorates over time due to traffic loading, environmental actions, aging processes, and structural degradation mechanisms (Morais et al., 2021a; Morais et al., 2026). To ensure safety, functionality, and service availability, maintenance and renewal interventions become necessary throughout the service life of these assets.

Effective maintenance management depends on the availability of reliable information regarding infrastructure condition and performance. Inspections, monitoring activities, and Performance Indicators (PIs) are commonly used to characterize infrastructure condition, support maintenance planning, and assist decision-making processes (Morais et al., 2021a; Morais et al., 2021b; Morais et al., 2026). The increasing availability of data has also created opportunities for the use of predictive approaches capable of supporting a more proactive management of infrastructure assets.

Although roadway and railway bridges share common challenges related to degradation and maintenance, the methodologies adopted for their assessment and management often differ. Differences may be observed in inspection procedures, information sources, condition assessment approaches, maintenance planning processes, and the use of predictive models (Matos et al. 2023; Matos et al. 2025). Consequently, maintenance decisions may be supported by different types of information depending on the infrastructure considered.

This paper compares two methodologies developed for bridge maintenance management, but for two network transportation types, namely roadway and railway. The first is an inspection and management framework developed for bridges and similar structures under the responsibility of a Portuguese municipality, with the roadway bridge component being considered in this study (Matos et al. 2024). The second is a predictive methodology developed within the In2Track2 Project for railway infrastructure management (Morais et al. 2021b; Morais et al., 2026). The comparison focuses on information sources, Performance Indicators, assessment approaches, and maintenance support processes. Based on the identified similarities and differences, the paper discusses how both methodologies contribute to maintenance management and how their information structures may support future digitalization efforts.

2. Performance Indicators in Transportation Infrastructure Management

Within the context of this paper, roadway and railway infrastructures are interpreted as coupled systems composed of: (i) a transportation infrastructure (pavement or railway track), (ii) a supporting structure (e.g., bridge), and (iii) external actions.

Traffic loading, environmental actions, aging processes, maintenance interventions, and structural deterioration influence infrastructure performance and degradation over time (Morais et al. 2021a; Morais et al. 2026). Understanding these interactions is essential to identify the variables governing infrastructure behaviour and to define representative Performance Indicators (PIs) (Morais et al. 2021a).

The evolution of PIs over time provides information regarding infrastructure degradation and future performance. Such information may be integrated with prediction models, monitoring systems, and digital tools to support maintenance planning and infrastructure management decisions (Morais et al. 2021a; Morais et al. 2026).

2.1. *Roadway infrastructure*

Roadway bridge management practices vary across infrastructure owners, regions, and countries. Differences may be observed in inspection procedures, condition rating systems, available data, and decision-making criteria, which may lead to different maintenance and intervention decisions. Examples from Italy, Portugal, and Slovakia show that, although the management objectives are similar, the adopted approaches differ in terms of rating scales, inspection periodicity, data availability, and prioritization criteria (Matos et al. 2023; Matos et al. 2025).

Different approaches have been proposed concerning PIs for roadway infrastructure. Two examples are the work developed within COST Action 354 for roadway pavements and COST Action TU1406 for roadway bridges (Litzka et al. 2008a; Litzka et al. 2008b; Matos et al. 2016).

Both approaches proposed a three-level performance framework. The transition from one level to the next is achieved through weighting procedures that combine variables and PIs into higher-level indicators.

In the first approach, variables describing pavement condition (longitudinal and transverse evenness, macro-texture, friction, bearing capacity, noise, air pollution, cracking, and surface defects) are combined to obtain safety, comfort, structural, and environmental PIs. These are subsequently aggregated into an overall PI (Litzka et al., 2008a; Litzka et al., 2008b).

In the second approach, the first level is focused on the data collected during bridge inspections. At the second level, the previous data are combined with aspects related to structural safety and serviceability, sustainability aspects associated with durability, and socio-economic aspects associated with traffic safety. At the third level, the importance of the asset within the transportation network is taken into consideration (Matos et al., 2016; Strauss et al., 2016; Stipanovic et al., 2017; Pakrashi et al., 2019).

2.2. *Railway infrastructure*

Railway track degradation is influenced by traffic loading, environmental conditions, and the heterogeneity of railway infrastructure, including curves, switches, crossovers, rail joints, support systems (e.g., bridges), and transitions between different support conditions. This heterogeneity results in variations in track stiffness and support conditions, influencing track behaviour and degradation mechanisms (Morais et al., 2021a; Morais et al., 2026).

Different approaches have been proposed concerning PIs for railway infrastructure. One example is the work developed within the In2Track2 Project (Morais et al. 2021b; Morais et al., 2026). The proposed approach identifies groups of PIs and performs data clustering to enable the forecasting of PIs with the aim of supporting maintenance and management decisions.

The PIs are subdivided into three types. The first type concerns the geometric deviations of the railway track and is subdivided into longitudinal level, alignment, cant, gauge, and twist. The second type concerns failures at component level and is subdivided according to the type of component considered. The third type concerns the environmental impact and possible problems associated with track operation during its service life, namely the day-evening-night noise level and the night-time noise level indicators (Morais et al., 2026). Correlations between PIs and the corresponding environmental and economic consequences are considered, making it possible to obtain a Reliability, Availability, Maintainability, and Safety (RAMS) interpretation of the results (Morais et al., 2026).

Several research projects concerning railway bridges have also been developed. One example is the SAFEWAY Project, in which dynamic risk-based predictive models were developed using performance indicators available in large databases to forecast infrastructure condition and support risk assessment and decision-making at both asset and network levels (SAFEWAY D5.1). However, unlike roadway bridges, no framework specifically focused on railway bridge performance indicators and their hierarchical aggregation for maintenance and asset management purposes was identified in the literature reviewed in this study.

3. Methodologies

3.1. *Roadway bridge inspection and management methodology*

The roadway methodology is based on an inspection and management framework developed for a Portuguese municipality, taking as reference selected principles adopted by the national infrastructure manager, Infraestruturas de Portugal (2025), while addressing the specific requirements of municipal infrastructure management (Infraestruturas de Portugal 2017; Matos et al. 2024). The objective is to support the collection, assessment, and updating of information required for bridge maintenance management (Matos et al. 2024).

To improve consistency and reduce subjectivity throughout the management process, taxonomies were developed. These taxonomies, together with dedicated inspection forms, support the collection, organization, classification, and interpretation of information obtained during inspections. The resulting structure facilitates condition assessment, diagnosis, maintenance planning, and subsequent decision-making processes, while contributing to a more uniform evaluation of the infrastructure over time (Matos et al. 2024).

The framework is organized into three consecutive phases (Figure 1). The first phase concerns the collection and review of available information. The second phase focuses on the assessment and documentation of the infrastructure condition. The third phase consolidates the collected information and supports the definition of condition ratings, recommendations, actions, and alerts (Matos et al. 2024).

The outputs of the methodology include condition assessments, inspection reports, maintenance actions, and alerts. The framework also supports the updating of information through successive inspection cycles, allowing the condition of the infrastructure to be reassessed as new information becomes available (Matos et al. 2024).

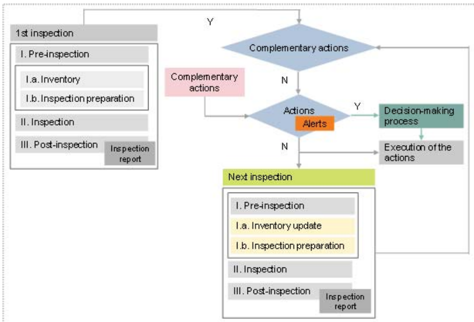

Fig. 1. Roadway bridge inspection and management framework showing the inspection cycle, maintenance actions, and information updating process (Matos et al. 2024).

3.2. *Railway infrastructure predictive methodology*

The railway methodology was developed within the In2Track2 Project with the objective of supporting the forecasting of railway infrastructure performance using inspection, monitoring, and operational data. The methodology focuses on the use of Performance Indicators (PIs) to evaluate degradation trends and support maintenance planning (Morais et al. 2021b; Morais et al., 2026).

The framework uses Performance Indicators obtained from inspections, measurements, monitoring systems, and available databases to characterize infrastructure condition, evaluate degradation trends, and support maintenance-related assessments. The resulting information supports the evaluation of future infrastructure condition and its potential consequences (Morais et al. 2021b; Morais et al., 2026).

The framework is organized into four consecutive phases (Figure 2). The first phase concerns the organization of available data. The second phase processes and groups the information according to the analysis requirements. The third phase forecasts the future evolution of infrastructure condition. The fourth phase evaluates the associated consequences and supports maintenance-related decisions (Morais et al. 2021b; Morais et al., 2026).

The outputs of the methodology include forecasts of infrastructure condition, consequence assessments, and information to support maintenance planning. The framework also allows the updating of predictions as new information becomes available (Morais et al. 2021b; Morais et al. 2026).

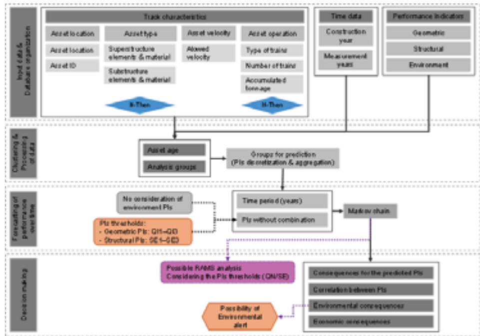

Fig. 2. Railway infrastructure predictive framework showing data organization, forecasting, and decision-support processes (Morais et al. 2021b; Morais et al. 2026).

Table 1 summarizes the main characteristics of the two methodologies. Although the roadway methodology focuses on condition assessment and maintenance management, and the railway methodology emphasizes predictive capabilities, both approaches use information to support maintenance planning. The implications of these similarities and differences are discussed in the following section.

4. Comparison and discussion

The comparison highlights important differences in the type and availability of information used by the two methodologies. The roadway approach relies primarily on inventory records, inspection observations, and historical information collected throughout successive inspection cycles. In contrast, the railway approach combines inspection information with measurements, monitoring data, and operational records that can be used to support predictive analyses. As a result, the available information influences both the assessment process and the maintenance decisions that can be supported.

The two methodologies also differ in their primary assessment objectives. The roadway methodology focuses on condition assessment and maintenance management based on inspection data. The railway methodology extends this perspective by incorporating predictive capabilities that support the evaluation of future condition states and their associated consequences. Although the approaches address different stages of the maintenance process, they should be viewed as complementary rather than competing methodologies.

Table 1. Comparison of the roadway and railway methodologies regarding information management, condition assessment, prediction capabilities, and maintenance decision support.

Aspect	**Roadway methodology**	**Railway methodology**
Main objective	Condition assessment and maintenance planning	Performance forecasting and maintenance planning
Primary information source	Visual inspections and historical records	Inspections, measurements and monitoring data
Information organization	Taxonomies and inspection forms	Performance Indicators
Assessment focus	Current condition and maintenance needs	Future condition and consequences
Main output	Condition ratings, actions and alerts	Forecasts and consequence assessments
Updating process	Successive inspection cycles	Updating of indicators and predictions
Maintenance approach	Condition-based maintenance planning	Prediction-based maintenance planning
Digitalization potential	Structured inspection workflow	Structured predictive workflow

Both methodologies contribute to maintenance decision-making using structured information and condition-related indicators. In the roadway methodology, the collected information supports the identification of damages, condition states, and maintenance actions. In the railway methodology, Performance Indicators are used to evaluate degradation trends and the potential consequences associated with future infrastructure conditions. In both cases, the resulting information helps prioritize interventions and maintenance resources.

Despite their different objectives, both methodologies require the collection, organization, and updating of information. This common characteristic supports future digitalization efforts. The use of organized data and periodic updates may facilitate the integration of predictive tools and monitoring systems.

The differences between the methodologies are also reflected in the way digitalization is applied. While both approaches rely on the collection and updating of information, digitalization contributes to improving the organization, accessibility, and use of that information within the assessment process. The systematic organization and updating of information required by both methodologies may also facilitate the integration of predictive tools, monitoring systems, and decision-support processes.

5. Final considerations

This paper compared two methodologies supporting the maintenance of roadway and railway bridges. The roadway methodology focuses on condition assessment and maintenance management based on inspection data, whereas the railway methodology incorporates predictive capabilities to evaluate future infrastructure conditions.

The comparison showed that the two approaches use different information sources and address different stages of the maintenance process. Nevertheless, both transform available data into information that can support maintenance planning and intervention prioritization.

The systematic collection, organization, and updating of information are common elements of both methodologies. These characteristics support future digitalization and contribute to more informed maintenance strategies for transportation infrastructure.

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