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Digitalization and Risk-Informed Bridge Management in Europe: A Comparative Study

Maria-José Morais
Department of Civil Engineering, University of Minho, ISISE, ARISE, Portugal. E-mail: id6741@alunos.uminho.pt

Hélder S. Sousa

Department of Civil Engineering, University of Minho, ISISE, ARISE, Portugal. E-mail: hssousa@civil.uminho.pt

José C. Matos

Department of Civil Engineering, University of Minho, ISISE, ARISE, Portugal. E-mail: jmatos@civil.uminho.pt

Jakub Kraľovanec

Department of Structures and Bridges, Faculty of Civil Engineering, University of Žilina, Slovakia. E-mail: jakub.*kralovanec@uniza.sk*

Vanni Nicoletti

Department of Construction, Civil Engineering, and Architecture, DICEA, Università Politecnica delle Marche, Italy. E-mail: v.nicoletti@staff.univpm.it

Fabrizio Gara

Department of Construction, Civil Engineering, and Architecture, DICEA, Università Politecnica delle Marche, Italy. E-mail: f.gara@staff.univpm.it

Martin Moravčík

Department of Structures and Bridges, Faculty of Civil Engineering, University of Žilina, Slovakia. E-mail: martin.moravcik@uniza.sk

Europe's transport infrastructure networks are facing increasing challenges in ensuring safety, reliability, and long-term performance, particularly as many bridges built during the mid-20th century approach the end of their service life. The transition toward digitalization represents a major opportunity to enhance risk-informed decision-making, predictive maintenance, and asset management.
This paper examines the current state and application of digital technologies, such as sensor networks, Internet of Things (IoT), Building Information Modelling (BIM), and Digital Twin (DT), in the management of roadway bridges across Italy, Portugal, and Slovakia, representing Southern, Western, and Central Europe. The study focuses on how these tools support condition monitoring, failure prognostics, maintenance optimization, and risk and reliability assessment.
Key enablers, including data acquisition infrastructures, standardized frameworks, and organizational readiness, are discussed alongside major barriers such as interoperability issues, data quality limitations, lack of harmonized performance metrics, and regulatory fragmentation. Through a comparative analysis, the paper highlights differences and commonalities among the three national approaches and proposes pathways toward a standardized, digitalized framework for bridge health management across Europe. The findings aim to support the development of more resilient, data-driven, and sustainable infrastructure management practices aligned with European digital transformation goals.

Keywords: European Transport Infrastructure, Digitalization, Bridge Management, Risk-Informed Decision-Making.

1. Introduction

Roadway bridges are essential elements of transportation networks, providing connectivity between regions and supporting the mobility of people and goods (Matos et al. 2023).

Throughout their service life, bridges are exposed to traffic loading, environmental actions, natural and man-made hazards, and ageing processes. Inadequate maintenance or delayed interventions may further accelerate their deterioration, affecting their condition, performance, and long-term serviceability (Morais et al. 2021).

Given their importance within transportation systems, bridge deterioration may have significant social and economic consequences (Matos et al. 2023).

Several bridge failures and collapse events have been reported in Europe over recent decades, causing traffic disruptions, increased transportation costs, and impacts on local communities, with some cases resulting in fatalities (Matos et al. 2023). These events highlight the importance of inspection, maintenance, and safety management throughout the service life of bridges (Matos et al. 2025).

Bridge management relies on large amounts of data generated throughout the service life of a structure through inspections, monitoring activities, testing, and maintenance actions. Digital tools and management systems facilitate the collection, storage, organization, updating, and use of these data. They can also support the planning of inspections and maintenance activities and contribute to decision-making related to roadway bridge management.

Across Europe, different approaches to roadway bridge management can be found, reflecting differences in institutional organization, management responsibilities, regulatory frameworks, and available digital systems.

This paper presents the current use of digital tools and systems supporting roadway bridge management in Italy, Portugal, and Slovakia. These countries were selected to represent different European roadway infrastructure management contexts, characterized by distinct institutional arrangements, management structures, and approaches to the implementation of digital systems supporting bridge management activities. The following sections present the institutional context of bridge management and the digital tools and systems supporting management and decision-making in the three countries, followed by a comparative analysis and discussion of the national contexts. The paper concludes with the main findings and final considerations.

2. Digitalization in Roadway Infrastructure Management in Italy

2.1. *Institutional Context*

In Italy, the management, operation, and maintenance of a significant part of the national roadway network, and consequently many roadway bridges, are under the responsibility of ANAS (Azienda Nazionale Autonoma delle Strade). The operation and maintenance of specific motorway sections and associated bridge structures are under the responsibility of motorway concessionaires. (Matos et al. 2023; ANAS 2025)

At local level, roadway bridges are managed by regional, provincial, and municipal administrative entities according to infrastructure ownership and administrative responsibility (Matos et al. 2023).

2.2. *Existing Digital Tools and Systems to Support Management and Decision-making*

Following the collapse of the Morandi Bridge in 2018, increased attention was given to bridge safety assessment, monitoring, and infrastructure management procedures in Italy.

The National Information Archive of Public Works, AINOP (Archivio Informatico Nazionale delle Opere Pubbliche), is a digital platform introduced in 2019 that supports the collection and management of information related to public

infrastructure, including bridges (Matos et al. 2025).

The management and safety assessment of existing bridges are also framed by the Italian Guidelines for risk classification and management, safety assessment, and monitoring of existing bridges, adopted through Ministerial Decree No. 578/2020 and updated by Ministerial Decree No. 204/2022 (Italian Ministry of Infrastructure and Transport 2020; Italian Ministry of Infrastructure and Transport 2022; Matos et al. 2023).

3. Digitalization in Roadway Infrastructure Management in Portugal

3.1. *Institutional Context*

In Portugal, the roadway network, and consequently roadway bridges, is divided into the National Road Network and the Municipal Road Network.

In the National Road Network, the management, operation, and maintenance of bridges are under the responsibility of Infraestruturas de Portugal (IP) and private concessionaires. IP operates under the General Concession of the National Road Network granted by the Portuguese State (Infraestruturas de Portugal 2025).

Private concessionaires and subconcessionaires, such as Brisa, Ascendi, and Lusoponte, are responsible for the operation and maintenance of specific roadway sections and associated bridge structures under concession regimes (Autoridade da Mobilidade e dos Transportes 2025).

In the Municipal Road Network, he management, operation, and maintenance of municipal roadway bridges are under the responsibility of municipalities. Municipal roadway bridge management practices may differ between municipalities, and associated methodologies and databases are generally not publicly accessible (Matos et al. 2025).

3.2. *Existing Digital Tools and Systems to Support to Management and Decision-making*

Following the collapse of the Entre-os-Rios bridge in 2001, increased attention was given to systematic inspection and maintenance management practices for transportation infrastructure in Portugal after 2002 (Pereira et al. 2021).

Looking at roadway bridges, Infraestruturas de Portugal (IP) uses management systems that support inventory, inspection, diagnosis, maintenance, and decision-making processes associated with roadway bridges under its responsibility (Pereira et al. 2021). Visual inspections are supported by unmanned aerial vehicles (UAVs), mini-UAVs for confined spaces, remotely operated vehicles (ROV) for underwater inspection, and uncrewed surface vehicles (USV) for bathymetric surveys near bridge foundations (Infraestruturas de Portugal 2017).

Some roadway concessionaires, such as Autoestradas do Atlântico concession, also use a management system (Mendonça et al. 2022; BETAR 2025).

Research projects and technical studies related to monitoring, structural health monitoring (SHM), Building Information Modelling (BIM), and digitalization approaches have also been applied to Portuguese roadway bridges. Examples include SHM studies on the 25 de Abril Bridge, Vasco da Gama Bridge, and Infante D. Henrique Bridge (Pereira et al. 2021; Clara 2025).

4. Digitalization in Roadway Infrastructure Management in Slovakia

4.1. *Institutional Context*

In Slovakia, roadway bridges are managed according to road category and ownership structure.

The Slovak Road Administration (SSC; Slovenská správa ciest), together with the National Highway Company (NDS; Národná diaľničná spoločnosť), is responsible for the management, operation, and maintenance of Slovakia's national road infrastructure, including

associated bridge management activities (Slovenská správa ciest 2025a).

Roadway bridges associated with regional and local road infrastructure are managed by the corresponding administrative entities according to infrastructure ownership and administrative responsibility (Slovenská správa ciest 2025a).

4.2. *Existing Digital Tools and Systems to Support to Management and Decision-making*

Bridge management activities in Slovakia are supported by the Road Network Information System, which includes a Bridge Application used for bridge-related technical information and inspection records (Slovenská správa ciest 2025b).

According to the Slovak Road Administration, the Bridge Application supports bridge-related technical information, inspection records, and bridge management activities associated with roadway bridges (Slovenská správa ciest 2025b).

Public statistical overviews of bridge condition are periodically published by the Slovak Road Administration based on information available in the Road Network Information System (Slovenská správa ciest 2025c).

5. Comparison and discussion

Digital systems are used in Italy, Portugal, and Slovakia to support bridge inventories, inspection activities, condition assessment, monitoring, and maintenance management. These functions constitute the common core of digitalization identified across the three national contexts.

The comparison showed that the main differences are not associated with the management functions supported by digitalization, but rather with the contexts in which these functions are implemented. Differences were identified in infrastructure management responsibilities, regulatory and procedural frameworks, management systems, and the availability of publicly accessible information. As a result, similar management objectives are achieved through different organizational arrangements and information environments.

The availability and accessibility of information emerged as an important aspect of the comparison. Information regarding management systems, digitalization practices, and implementation procedures is not equally accessible across infrastructure managers and countries. Consequently, the visibility of digitalization initiatives may not necessarily reflect their actual level of implementation, introducing an important limitation when comparing practices between different national contexts.

The comparison indicates that similar roadway bridge management functions are supported through different governance structures, management responsibilities, and information environments. Therefore, differences in digitalization practices should be interpreted within the institutional and organizational contexts in which they are implemented.

The comparison is based primarily on publicly available information. Consequently, differences in publicly accessible documentation may influence the visibility of digitalization practices and systems across countries and infrastructure managers and may not necessarily reflect differences in their actual implementation.

Table 1 summarizes the main bridge management responsibilities, digital systems, and management functions identified across the three national contexts.

Table 1. Summary of bridge management responsibilities, digital systems, and management functions identified in Italy, Portugal, and Slovakia.

Country	Main bridge managers	Digital systems	Inspection records	Monitoring / SHM	Assessment & decision support
Italy	ANAS; motorway concessionaires; local authorities	AINOP	Integrated in management procedures	Monitoring procedures identified	Risk classification; assessment; management procedures
Portugal	IP; concessionaires; municipalities	IP systems; concessionaire systems	Integrated in management systems	Monitoring and SHM reported for specific bridges	Inspection; diagnosis; maintenance; decision-making
Slovakia	SSC; NDS; regional and local authorities	Road Network Information System; Bridge Application	Integrated in Bridge Application	Limited publicly available information identified	Condition records; bridge management activities

6. Final considerations

This paper reviewed the current use of digital tools and systems supporting roadway bridge management in Italy, Portugal, and Slovakia. In the three countries, digital systems are used to support bridge inventories, inspection activities, condition assessment, monitoring, and maintenance management.

The comparison identified common management functions supported by digital information across the three countries. However, differences were observed in infrastructure management responsibilities, regulatory and procedural frameworks, management systems, and the availability of publicly accessible information regarding digitalization practices and applications. These results show that similar management objectives may be addressed through different institutional and organizational arrangements.

The study also highlighted that information regarding digitalization practices, management systems, and implementation procedures is not equally accessible across infrastructure managers and countries. Consequently, the visibility of digitalization initiatives may not necessarily reflect their actual level of implementation, representing an important limitation for comparative analyses based on publicly available sources.

The comparative analysis showed that differences in digitalization practices are influenced not only by the digital tools and systems adopted, but also by the institutional, organizational, and regulatory contexts in which they are implemented.

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