PREDICTIVE INSPECTION AND MAINTENANCE METHODS OF WATERBORNE INFRASTRUCTURE

TERMS OF REFERENCE

1. Background

Inland waterway (IW) and maritime transport reliability depends heavily on the performance of a broad range of the waterborne infrastructure, including locks, navigation weirs, movable bridges, river training and port structures, bank protection works, mooring facilities, navigation aids, and associated mechanical, electrical, automation and control systems.

Worldwide, many waterborne infrastructure assets are approaching or exceeding their original design life. In addition, these assets are increasingly exposed to changes of operational demands, higher expectations for availability and safety, ageing-related deterioration, limited maintenance resources, and the impacts of climate change, including more frequent floods, prolonged low-water periods and more variable hydraulic loading conditions. These challenges increase the need for more reliable, efficient and forward-looking approaches for inspection and maintenance.

Traditional inspection and maintenance practices are often based on fixed inspection intervals, visual assessment, condition scoring and time-based or corrective maintenance. These practices remain essential. But these approached are not always sufficient to anticipate the future asset performance, understand degradation mechanisms, or optimise the timing and prioritisation of maintenance interventions. In particular, a simple "inspect–score–act" approach may not adequately reflect asset criticality, functional performance, reliability requirements, failure consequences or network-level impacts.

Modern infrastructure asset management is increasingly moving towards risk-informed, reliability-based and performance-oriented maintenance strategies. These approaches integrate asset functions, service requirements, degradation mechanisms, failure modes, inspection findings, monitoring data, operational information and risk assessment into a coherent decision-making framework. Therefore, **predictive inspection and maintenance** represents an advanced stage of asset management maturity, where the evolution of asset condition and performance can be assessed, monitored or forecast to support proactive intervention planning.

The application of digital technologies, including structural health monitoring, SCADA systems, sensor networks, asset information systems, dashboards and digital twins, and now Artificial Intelligence (AI) offers new opportunities to improve inspection and maintenance decision-making. However, such technologies should be applied with clear objectives and should be linked to specific asset management questions, failure mechanisms and decision needs. Predictive maintenance should not be understood simply as the installation of sensors or the creation of a database, but as a systematic process linking data, degradation, reliability, risk and maintenance decisions.

To address these challenges, a PIANC Working Group (WG) on Predictive Inspection and Maintenance of Waterborne Infrastructure is proposed. The WG will bring together international experts to review current and advanced practices, compare methodologies, analyse representative case studies and develop practical guidance for implementing predictive inspection and maintenance strategies for IW infrastructure under different technical, organisational and resource conditions.

2. Objectives

After the review and comparison of the current existing methods, the main objective of the WG is to discuss **internationally applicable guidance for predictive inspection and maintenance of waterborne infrastructure**, based on principles of asset management, reliability engineering, risk management and performance optimisation.

This initiative seeks to:

- Establish a common terminology and conceptual framework for predictive inspection and maintenance of waterborne infrastructure.
- Review current and advanced international practices in inspection, monitoring, condition assessment, maintenance planning and asset management.
- Develop a systematic framework linking asset functions, service levels, degradation mechanisms, failure modes, inspection strategies, monitoring systems, risk assessment and maintenance decision-making.
- Identify suitable inspection, testing and monitoring approaches for different categories of waterborne infrastructure assets.
- Examine how operational data, structural health monitoring, SCADA systems, digital asset databases, dashboards and digital twins, AI, can support predictive maintenance strategies.
- Provide practical guidance for integrating condition information, reliability indicators, asset criticality and risk evaluation into maintenance planning and prioritisation.
- Develop implementation pathways suitable for organisations with different levels of data availability, technical capacity and asset management maturity.
- Compile international case studies and lessons learned to support practical application.

This should be done in collaboration with existing running PIANC WGs such as WGs 233, 257, 264, 271, .. (see more in next section), avoiding duplication, and published PIANC WG reports (such as WGs 25, 129, 199, 206, 255, ...).

3. Earlier reports to be reviewed

The WG should review and build upon relevant PIANC reports, including but not limited to:

- PIANC WG 25 : Maintenance and Renovation of Navigation Infrastructure
- PIANC WG 129 :Waterway Infrastructure Asset Maintenance Management
- PIANC WG 199 : Health Monitoring of Port and Waterways Structures
- PIANC WG 206: Design of Navigation Locks
- PIANC WG 233: Inspection, Maintenance and Repair of Waterfront Facilities
- PIANC WG 255: Structural Re-assessment of Existing Hydraulic Structures
- PIANC WG 257: Digital Twins for Waterborne Transport Infrastructure (still running)
- PIANC WG 264: Innovative Digitalisation Approaches for Managing Hydraulic Structures of Inland Waterways
- PIANC WG 271: IW Strategies for Navigation Availability Assessment

and

- RWS - Baijens Marloes (RWS PPO) , Koedijk Otto (RWS WVL) https://www.operationalexcellence.nl/rcm/
- BAW Maintenance methodology (see papers of C Kunz, AnneMarie Seiffert, BAW,DE)
- VNF 2024- Benchmark of Asset management methods in waterways
- Work undertaken within CEN/TC 319 - *studies and standards* -
- International standards, technical specifications and guidance documents related to asset management, maintenance management, reliability-centred maintenance, risk-based inspection, structural health monitoring, condition assessment, maintenance documentation, digital asset management and information governance.

4. Scope of Work

The WG will focus on predictive inspection and maintenance of waterborne infrastructure from a systems-based asset management perspective. The scope includes technical, organisational and decision-support aspects necessary to establish effective predictive maintenance frameworks.

The WG will consider a broad range of waterborne infrastructure assets, including:

- Navigation structures such as locks, navigation weirs, lock and weir gates, movable bridges, mooring facilities and associated waterborne structures;
- Port, coastal and offshore structures linked to maritime transportation;
- Civil and river engineering structures such as retaining walls, guide walls, quay walls, embankments, bank protection works, groynes and related infrastructure;
- Mechanical and electrical systems such as drive systems, hydraulic systems, electrical installations, power supply systems and auxiliary equipment;
- Automation, control and communication systems such as signalling systems, SCADA systems, sensors, instrumentation and control components;
- Associated environmental and multifunctional infrastructure where relevant.

The WG will recognise that different asset categories have different functions, degradation mechanisms, inspection requirements, monitoring needs, reliability characteristics and failure consequences. A single condition index or inspection approach may not be suitable for all asset types.

The WG will focus on the following main themes:

- Asset classification, functions and service requirements;
- Degradation mechanisms, deterioration processes and failure modes;
- Inspection, testing and monitoring strategies (WG233);
- Reliability-centred maintenance and risk-based inspection;
- Condition assessment, criticality assessment and risk evaluation;
- Prognostic approaches and predictive maintenance methodologies;
- Integration of operational data, maintenance records and monitoring information;(see PIANC WG 199);
- Digital tools, including asset information systems, dashboards, SCADA systems, digital twins (see PIANC WG 257, WG 264), and AI;
- Data governance, data quality, interoperability and access management;
- Implementation pathways for different organisational and technical contexts;
- International case studies and practical applications.

The WG will not develop detailed design standards for specific infrastructure components. It will not prescribe national regulations, statutory inspection procedures, specific software platforms or proprietary technologies. It will also not replace the responsibilities of asset owners

or competent authorities. Close collaboration with WG 264 on digitalisation will be mandatory (for instance for Cybersecurity issue).

5. Intended product

The WG will produce a PIANC technical report providing practical guidance on current existing methods and on predictive inspection and maintenance of IW infrastructure. It will be a complementary guideline to WG 233 (Inspection, Maintenance and Repair) which will be soon issued by MARCOM.

The report will present a common terminology, an asset classification, and a risk- and reliability-informed framework linking asset functions, degradation mechanisms, inspection, monitoring, condition assessment and maintenance decision-making.

The report will include representative international case studies and practical recommendations for waterway and port authorities, infrastructure owners, operators and asset managers.

6. WG membership

The WG should include experts from IW and ports authorities, infrastructure owners and operators, asset managers, maintenance specialists, inspection and condition assessment experts, structural health monitoring specialists, reliability and risk assessment experts, civil, mechanical, electrical and control-system engineers, digital asset management and AI specialists,..

Participation from different regions and institutional contexts should be encouraged to ensure that the recommendations are internationally applicable and reflect different levels of technical capacity, data availability and resource constraints.

7. Target Audience

The report is intended for IW and port authorities, infrastructure owners and operators, asset managers, maintenance managers, inspection organisations, engineering consultants, designers, contractors, policy makers and technical specialists.

It will provide practical guidance for organisations responsible for maintaining the safety, reliability, availability and long-term performance of waterborne infrastructure.

8. Relevance

The report will be particularly useful for countries and regions facing ageing infrastructure, limited maintenance budgets and incomplete asset information.

Relevance to Countries in Transition

The report will provide a practical framework for improving inspection and maintenance prioritisation under different levels of data availability and institutional capacity. It will help authorities make better use of limited resources, reduce unexpected failures and improve the reliability of existing waterborne infrastructure without relying only on costly reconstruction.

Relevance to Climate Change

Predictive inspection and maintenance can support climate adaptation by improving understanding of asset vulnerability, enabling early intervention and strengthening network resilience.

Relevance to Working with Nature

Extending the service life of existing waterborne infrastructure, where technically and economically justified, can reduce the need for major reconstruction and associated environmental impacts. Better understanding of degradation processes, asset performance and maintenance needs can support more sustainable infrastructure management and reduce unnecessary interventions in river and port systems.

Relevance to Sustainable Development Goals (SDGs)

This report directly supports several Sustainable Development Goals:

- **SDG 8** – Decent Work and Economic Growth: by improving the reliability of IW transport and supporting efficient logistics.
- **SDG 9** – Industry, Innovation and Infrastructure: by promoting resilient infrastructure, innovation and modern asset management.

Overall, the WG report will support the transition from reactive and interval-based maintenance towards more risk-informed, reliability-based and predictive maintenance strategies. This will contribute to safer, more resilient, more efficient and more sustainable IW infrastructure management.