

# ABSTRACT

## Review of Asset Management System and New Implementation Model of a Case Study on Indonesian National Bridges

Effective bridge asset management has become increasingly critical in Indonesia as the national road network continues to expand and infrastructure investments rise to support economic growth, regional connectivity, and disaster resilience. Bridges constitute a vital component of this network, enabling mobility across Indonesia's diverse geography and supporting transportation corridors essential to economic activities. However, despite the increasing emphasis on infrastructure development, persistent challenges continue to limit the effectiveness of bridge management practices. These challenges include insufficient managerial capacity, inadequate technical resources, fragmented institutional responsibilities, and the absence of an integrated, standardized system capable of supporting long-term maintenance planning. As a result, many asset managers are constrained in their ability to apply data-driven decision-making frameworks, leaving Indonesia's bridge preservation activities largely reactive and budget-dependent.

Bridge asset management is a critical component of national road governance, requiring a reliable data input system to ensure accurate decision-making and the selection of appropriate preservation strategies for each structure. As of 2022, Indonesia's national road network spans 46,964 km and includes 19,241 bridges (6 meters and longer) under the management of the Directorate General of Highways at the Ministry of Public Works and Public Housing. To carry out bridge inspections, the Directorate General relies on consultants contracted directly by national road managers. This arrangement necessitates stringent oversight to ensure that field inspectors possess the required competencies and perform assessments to an acceptable standard.

In recent years, several unexpected bridge failures have occurred, primarily caused by overloading and scouring of bridge elements. These incidents prompted a reassessment of current bridge condition survey practices in Indonesia. The evaluation revealed several critical issues, most notably that inspectors often fail to conduct inspections with sufficient detail. This was evident from the large number of structural defects, many of them critical, that were not recorded in the detailed condition reports, despite requiring close examination.

Such omissions lead to highly subjective condition ratings and undermine the reliability of inspection results. As a consequence, when incomplete or inaccurate inspection data are used to support maintenance programming within Indonesia's bridge management system, the resulting decisions may be inappropriate or ineffective. These findings highlight the urgent need to strengthen inspection practices to ensure that maintenance planning is based on accurate, comprehensive, and objective condition information.

The development of Indonesia's bridge management system is still evolving and requires significant refinement. A variety of tools are currently used to assist managers in determining appropriate preservation strategies, yet the country is still in the process of formulating an accurate deterioration prediction model. Persistent challenges remain, particularly concerning the reliability of visual inspection data, which is frequently affected by inspector subjectivity. Additionally, the outcomes of bridge preservation programming have not been adequately validated through user feedback, leading these programs to be regarded more as budgetary

limits than as technical planning references. In practice, many bridge managers still struggle to apply these preservation strategies effectively within the constraints of available funding.

The issues outlined above underscore the need for a comprehensive study aimed at improving the objectivity of bridge inspections in Indonesia. Such improvements will also support the development of decision trees and deterioration models, enabling bridge maintenance programming to become more accurate, efficient, and aligned with the goal of achieving optimal service life.

To conduct further analysis, a comparative asset management framework is required to evaluate the strengths and weaknesses of Indonesia's current system. A suitable benchmark is Japan's Bridge Management System, particularly that used in Kochi Prefecture. Kochi faces challenges similar to Indonesia in developing its bridge management system, but it offers a unique example due to its stand-alone platform capable of calculating 100-year life cycle costs using a high-precision LCC optimization program. This system evaluates each bridge element based on its actual physical condition, enabling managers to select appropriate maintenance actions, maintain bridge performance at predefined service levels, and determine the most suitable preservation strategies through straightforward condition corrections and cost estimations.

Although both Indonesia and Japan rely on visual inspection data as the basis for maintenance programming, their assessment approaches differ substantially. Japan employs a physical evaluation method that classifies deterioration strictly according to the type and severity of observed damage. Indonesia, by contrast, incorporates not only damage type and severity but also the functional role of the affected element and the potential impact on other structural components. As a result, Indonesia's approach is characterized as a non-physical method of assessing bridge element condition. This comparative analysis is essential to determining whether Indonesia's current bridge management system requires improvements to enhance the reliability of maintenance programming outcomes and ensure that resulting decisions are both technically sound and strategically appropriate.

To address these issues, this study provides a comprehensive evaluation of the current state of bridge asset management in Indonesia by investigating five essential determinants of management effectiveness: budget availability, data quality, policy framework, resource capacity, and the management system infrastructure. These determinants collectively shape the operational environment in which asset managers operate and fundamentally influence their ability to implement strategic maintenance planning. Within this framework, particular emphasis is placed on the behavioral dimension of asset managers' decision-making, which is examined using principles of the Theory of Planned Behavior (TPB). The study analyzes how three psychological constructs, attitude toward behavior, subjective norms, and perceived behavioral control (PBC), affect the intention to perform effective asset management. Findings consistently indicate that perceived behavioral control, mediated by factors such as budget stability, data reliability, and the availability of skilled personnel, functions as the strongest determinant. Compared to attitude and subjective norms, PBC exerts the greatest influence by enhancing the confidence of asset managers in their ability to perform inspection, prioritization, and planning tasks, particularly under resource-constrained conditions.

Parallel to the behavioral assessment, this study explores the applicability of Life Cycle Cost Analysis (LCCA) within Indonesia's bridge management context. LCCA has been widely applied in advanced asset management systems worldwide, particularly in Japan, where the High-Precision Life Cycle Cost Analysis (HP-LCCA) model has become a cornerstone of long-term infrastructure stewardship. Unlike traditional approaches, HP-LCCA integrates multi-segment condition evaluations of bridge elements, allowing deterioration to be assessed at a granular level. This segmentation method captures the spatial variability of damage across bridge girder components, offering more reliable predictions of future condition states and

associated maintenance costs. The segmentation-based model has demonstrated strong capabilities in optimizing treatment timing, intervention selection, and cost minimization across the asset life cycle. This study evaluates how such a methodology could be adapted to Indonesia, where the existing Non-Physical evaluation model, characterized by aggregated scoring practices, may lack the precision necessary for high-resolution deterioration modeling.

A core component of the analysis involves a systematic comparison of Non-Physical and Physical visual inspection methods. Although these two approaches differ fundamentally in terms of assessment basis, scale, and damage quantification criteria, this study reveals that a generally linear correlation can be established between them. This correlation remains consistent across both concrete and steel girder bridges, indicating that Non-Physical evaluations can be meaningfully interpreted relative to the more detailed Physical method. However, the analysis also shows that variations in damage quantity and extent cause substantial divergence in objectivity between the two models. These discrepancies largely arise from the differing definitions of damage extent used in each method, which have implications for condition rating precision. The study finds that these methodological differences diminish significantly once segmentation is incorporated into the evaluation process. When condition assessments are performed at the segment level, both Physical and Non-Physical models converge more closely in terms of predictive alignment, demonstrating the value of adopting a more detailed evaluation framework.

The application of segmentation to bridge girder assessments produced notable improvements in the accuracy of Life Cycle Cost estimates. In particular, segmentation enabled the model to capture the localized distribution of deterioration, which is often obscured in aggregated condition ratings. This capability proved especially beneficial for bridges exhibiting non-uniform damage patterns, where deterioration is concentrated in specific segments rather than evenly distributed across an entire girder. For such cases, segmented HP-LCCA consistently produced minimum LCC outcomes, identifying targeted treatments that reduce unnecessary interventions and optimize long-term costs. Conversely, for bridges exhibiting uniform deterioration, segmentation yielded limited cost reduction benefits, suggesting that the value of high-precision modeling depends on the spatial characteristics of observed damage. Collectively, these findings reinforce the practical advantage of applying segmented Physical evaluations in Indonesia's future bridge management framework.

The implications of this study extend beyond technical assessment to broader strategic and organizational considerations. By demonstrating a workable correlation between the Non-Physical and Physical models, this research validates the possibility of integrating Indonesia's existing inspection system with a more advanced, high-precision deterioration modeling framework. This finding is crucial because Indonesia currently relies heavily on Non-Physical evaluations for nationwide inspections, and a complete shift to Physical evaluations would require substantial investments in training, tools, and human resources. The ability to bridge the two evaluation frameworks through correlation enables a transitional pathway, permitting Indonesia to gradually introduce higher-resolution methods without abandoning existing datasets or overwhelming local agencies.

Moreover, integrating segmented assessments into Indonesia's bridge management system offers significant potential for improving objectivity, predictive accuracy, and budget efficiency. By shifting from generalized, assumption-driven deterioration estimates to models based on spatially detailed condition information, asset managers will be better equipped to prioritize interventions, reduce uncertainty, and justify budget needs based on quantifiable life-cycle benefits. This approach aligns with global best practices and promotes more transparent, accountable decision-making within the public infrastructure sector.

The behavioral component of this study provides further insight into the success conditions for implementing HP-LCCA. Asset managers' willingness to adopt new methodologies is

strongly shaped by perceived behavioral control, which is influenced by budget adequacy, data reliability, and the presence of qualified personnel. Thus, improving data quality through validation and verification processes, ensuring stable budget allocations for maintenance work, and strengthening the capacity of local inspectors and engineers are essential prerequisites for successful implementation. Without these enabling conditions, even technically advanced systems may fail to deliver their intended benefits.

Furthermore, the study identifies important psychological and organizational dynamics within the broader ecosystem of bridge management in Indonesia. Local inspectors, who are responsible for data collection, often face limitations related to workload, training, and consistency in visual evaluation. These factors influence the accuracy of Non-Physical assessments and, by extension, affect the reliability of deterioration modeling. Bridge experts and senior technical managers, while supportive of more advanced methods, are themselves constrained by inconsistent policies and uneven institutional support across regions. Consequently, national-level reforms must incorporate both technical adjustments and organizational capacity-building measures to ensure the long-term sustainability of improvement efforts.

The findings of this study contribute to the growing recognition that effective bridge asset management requires more than technological sophistication; it requires a balanced integration of behavioral readiness, data governance, institutional coordination, and financial sustainability. As Indonesia seeks to modernize its national bridge management practices, the adoption of HP-LCCA represents a significant opportunity to improve long-term performance and reduce maintenance expenditures through proactive planning and precision-based deterioration modeling. The study demonstrates that even within existing resource constraints, meaningful enhancements can be achieved through selective applications of segmentation and structured correlation between the two evaluation methods.

In conclusion, this research highlights the pressing need for Indonesia to establish a more standardized, objective, and data-driven bridge asset management framework. The correlation between Non-Physical and Physical evaluations provides a foundation for integrating current practices with more advanced methodologies, while segmentation enhances the precision of both condition assessments and cost estimations. The central role of perceived behavioral control underscores the importance of strengthening managerial confidence through improvements in budget stability, data quality, and workforce capability. The successful implementation of HP-LCCA within Indonesia's bridge management system will not occur automatically; it will depend on deliberate institutional reforms, sustained capacity development, and a systematic alignment of policies, resources, and technological tools. Nonetheless, the findings affirm that with appropriate adjustments, Indonesia is well positioned to adopt high-precision deterioration modeling techniques that support more sustainable, cost-efficient, and adaptive bridge maintenance strategies for the future.