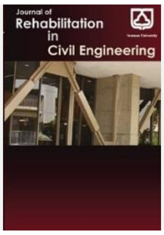

Journal of Rehabilitation in Civil Engineering

Journal homepage: https://civiljournal.semnan.ac.ir/

Development of Work Breakdown Structure (WBS) – Based Quality Management System for Concrete Bridges Maintenance Works to Improve Maintenance Performance

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ARTICLE INFO

Article history:
Received: 23 October 2024
Revised: 26 November 2024
Accepted: 14 January 2025

Keywords:
Bridge maintenance;
Work breakdown structure;
Maintenance performance;
Maintenance work;
Quality management system (QMS).

ABSTRACT

The state of bridges in Indonesia is concerning, with only 1.2% of the 18,990 national bridges classified as being in good condition. A significant number of bridge failures stem from inadequate maintenance, highlighting the urgent need for a structured and effective quality management approach. This research develops a Work Breakdown Structure (WBS)-based Quality Management System (QMS) framework specifically for concrete bridge maintenance to enhance performance and ensure adherence to national standards. The QMS encompasses three main stages—inspection, maintenance, and rehabilitation—comprising 10 activities systematically aligned with bridge maintenance requirements. Quantitative findings from expert validation showed high suitability of the QMS framework, with average scores of 4.0 to 5.0 across content, format, and performance effectiveness. Statistical analysis with 33 respondents revealed a strong positive correlation (r = 0.768) between the QMS and key maintenance performance indicators such as structural safety and bridge importance, explaining 54.9% and 59.9% of the variance, respectively. Qualitative insights emphasized the enhanced organization and durability of maintenance processes, supported by 10 Standard Operating Procedures (SOPs), work instructions, and checklists. This study's novelty lies in integrating WBS into QMS for concrete bridge maintenance, providing a structured methodology for achieving consistent and high-quality outcomes. The implementation of this framework is anticipated to significantly improve the safety, reliability, and sustainability of bridge infrastructure in Indonesia.

E-ISSN: 2345-4423

How to cite this article:
Laksono, N. Budi, Mashito, F. K. Januar, Latief, Y and Trigunarsyah, B. (2026). Development of Work Breakdown Structure (WBS) – Based Quality Management System for Concrete Bridges Maintenance Works to Improve Maintenance Performance. Journal of Rehabilitation in Civil Engineering, 14(1), 2194 https://doi.org/10.22075/jrce.2025.35701.2194

1. Introduction

For centuries, bridges have been fundamental to human civilization, serving as crucial links that facilitate the movement of people [1], goods, and services across natural barriers such as rivers, valleys, and oceans. Globally, bridges play an essential role in economic development, connecting urban centers, rural areas, and even entire nations [2]. According to the World Economic Forum (2021), modern bridges are an integral part of infrastructure systems that support global supply chains, trade, and economic growth [3]. With the global population steadily increasing and urbanization accelerating at an unprecedented rate, the demand for resilient and reliable bridge infrastructure is higher [4]. However, challenges such as climate change [5], aging infrastructure [6], and increased traffic loads pose significant threats to the structural integrity of bridges worldwide [7]. These challenges underscore the importance of implementing effective maintenance and management systems to ensure public safety and long-term sustainability [8].

Despite the increase in the number of bridges, their condition in Indonesia remains concerning. According to the Ministry of Public Works and Housing (PUPR) (2022), there are 18,990 bridges on national roads [9], with 15.31% in poor or damaged condition. Many bridges suffer from light to severe damage, highlighting the need for better maintenance and quality management. The deterioration of bridges, as observed over the years, poses significant risks to public safety and infrastructure reliability [10]. Bridge failures are a recurring issue in Indonesia, often as a result of poor quality management and inadequate maintenance practices [11]. One of the primary causes of these incidents is the heavy traffic that imposes excessive loads on structures, which many bridges are not equipped to handle [12]. Moreover, the degradation of materials, compounded by insufficient maintenance, further increases the risk of collapse [13]. The Kutai Kartanegara bridge collapse in 2011 is a notable example of such failures, demonstrating the devastating effects at the micro, mezzo, and macro levels, from individual losses to national economic impacts.

To prevent further bridge failures, it is important to implement a QMS to monitor and maintain bridge conditions [14]. An effective QMS ensures that inspections and maintenance are conducted according to established standards, thereby minimizing the risk of collapse [15]. As highlighted by various studies, the durability and structural performance of infrastructure, including concrete and reinforced beams, depend significantly on systematic maintenance and timely interventions [16]. For instance, Mortazavi and Shakiba (2023) emphasized the importance of proper reinforcement in RC beams for enhancing structural integrity [17]. A robust QMS is essential for managing construction quality and maintaining the safety and longevity of bridge structures [18]. Regular inspections and timely interventions are key to ensuring that bridges remain in optimal condition for public use [19]. Considering the growing concerns over bridge conditions in Indonesia [9], this research aimed to explore the development of a QMS WBS-Based as a novelty, specifically for the maintenance and preservation of concrete bridges. By improving the existing QMS, the objective of this research is to improve the performance and durability of bridges, reducing the risk of failure and ensuring that they continue to serve as critical infrastructure [19,20].

2. Literature review & hypotheses development

2.1. Work breakdown structure of concrete bridge maintenance

Work Breakdown Structure (WBS) is an important tool used in project management to organize the project's scope into manageable sections. According to the PMBOK Guide (2000), WBS is defined as a deliverable-oriented grouping of project elements that defines the scope of work [21].

In bridge maintenance, WBS helps define the scope by breaking down the work into components, making the project easier to manage and control [22]. For example, maintenance of a concrete bridge's superstructure involves several tasks that are part of a hierarchical system. Based on the previous WBS research outlines a 5-level hierarchy for bridge maintenance, with Level 1 being the "Project Name" and Level 5 being the most detailed activity.

Table 1 below shows an activity classification that will be a basis for maintaining and rehabilitation of a concrete bridge, while the details of the WBS will be attached in Appendix A

Table 1. Bridge Maintenance Work Activities Classification.

Project Name	Work Package	Work Scope	Reference
Bridge Maintenance Work	Bridge Inspection Work	Inventory Inspection	(PUPR, 2022), (Jasa Marga, 2022)
		Detailed Inspection	(PUPR, 2022), (Jasa Marga, 2022)
		Regular Inspection	(PUPR, 2022), (Jasa Marga, 2022), (JICA, 2018),
		Special Examination	(PUPR, 2022), (Jasa Marga, 2022)
	Maintenance (Preventive)	Regular Maintenance	(PUPR, 2018), (FHWA, 2018), (JICA, 2018)
		Periodic Maintenance	(PUPR, 2018), (Erbiyik. 2022)
	Rehabilitation (Corrective)	Repair	(JICA, 2018)
		Replacement	(PUPR, 2022), (Wu C., et al, 2021), (FHWA, 2018)
		Element Modification	(PUPR, 2022)
		Reinforcement	(JICA, 2018), (Wu C., et al, 2021)

The use of WBS enables more efficient management of bridge maintenance projects [23,24]. WBS facilitates the clear assignment of responsibilities, effective resource allocation, and the simplification of management processes. By breaking down tasks into smaller, manageable components, WBS ensures that all necessary maintenance elements, such as inspection of main girders and pavements, are considered to ensure the bridge's longevity and safety.

2.2. Concept of quality management system

A QMS is a structured framework of coordinated activities designed to ensure consistent delivery of products or services that meet customer and regulatory requirements [18]. According to ISO 9001:2015, a QMS enables organizations to systematically manage processes, ensuring efficiency, effectiveness, and continuous improvement. According to the Indonesia Ministry of Public Works and Housing (PUPR), a QMS refers to a system consisting of coordinated activities aimed at directing and controlling an organization in terms of quality [25]. In the implementation of a QMS, the following components are essential in the development phase:

2.2.1. Quality policy

The quality policy forms the backbone of an organization's commitment to implementing a QMS [26]. In line with global standards such as ISO 9001:2015, the quality policy is essential for directing activities aimed at improving overall performance, reducing inefficiencies, and ensuring that services meet or exceed stakeholder expectations [26]. To effectively implement the quality policy, all personnel must strive to improve processes, minimize failures, improve the competency of human resources, and continuously meet required service standards. This commitment to quality should be understood and actively adopted across all levels of the organization.

2.2.2. Quality objectives

Quality objectives translate the organization’s commitment to quality into measurable targets [27]. According to ISO 9001:2015, these objectives must be in line with the quality policy, be measurable, and focus on improving service conformity and customer satisfaction [28]. According to the specifications derived from the SMART framework (Specific, Measurable, Achievable, Realistic, and Time-bound), quality objectives are set by top management and tailored to the vision and mission of each unit. These specifications are regularly monitored and evaluated to ensure they remain relevant and achievable, promoting continuous improvement at all levels [28].

2.2.3. Standard operating procedures (SOP)

Standard Operating Procedures (SOPs) are important documents outlining the specific methods necessary to ensure consistent quality across an organization [29]. These procedures serve as a foundation for maintaining quality control and ensuring compliance with both internal and external requirements [30]. Subsequently, SOPs should cover key elements such as objectives, scope, roles, and responsibilities, and must be approved by top management to guarantee their applicability. This ensures that all work units adhere to standardized processes, ultimately leading to a more efficient and effective operation.

2.2.4. Work instructions

Work Instructions (WI) provide detailed guidelines on performing specific tasks to meet quality standards. Developed by experienced personnel and approved by top management, WI are designed to ensure accuracy and consistency across various activities [31]. The WI provides step-by-step instructions and may include flowcharts for clarity, ensuring that all processes are in line with the organization's quality objectives. These instructions are important for ensuring that tasks are performed correctly and efficiently, particularly in complex or high-risk operations.

2.2.5. Checklists & quality records

Checklists are practical tools used to verify that all necessary tasks have been completed according to defined standards [22]. As highlighted in the Project Management Body of Knowledge (PMBOK), checklists promote consistency and quality by ensuring that all important steps are followed and no key tasks are missed. Checklists can range from quality assurance to equipment inspections and risk assessments, providing a simple and effective method for maintaining control over processes and ensuring project success. Therefore, Quality records serve as evidence that a QMS has been properly implemented. These records include documentation such as reports, drawings, photos, and minutes of meetings, and these records provide transparency and accountability throughout the organization [32]. Quality records are essential for audits and reviews, ensuring that all processes are traceable and are in line with established standards.

2.2.6. Quality manual

The Quality Manual is a comprehensive document that governs the implementation of a QMS across all units of the organization. This manual includes the scope of a QMS application, quality objectives, and process interactions that support quality assuorrance. The Quality Manual is periodically updated to reflect changes in a QMS, ensuring that it remains relevant and effective. This document is a key reference for maintaining quality standards and guiding the organization towards continuous improvement [25].

2.3. Bridge maintenance performance indicator

Bridge maintenance performance is a critical metric used to evaluate the effectiveness of bridge maintenance and repair activities. To evaluate the performance of bridge maintenance and repair, specific indicators are necessary to serve as evaluation tools for the results of such activities. Performance indicators are measures accompanied by a rationale and realistic objectives, facilitating effective diagnostic processes and supporting appropriate decision-making within diverse organizational structures [33]. According to Ivankovic (2021), there are 6 important performance indicators for bridges, as follows [34]:

2.3.1. Structural safety

Structural safety is an indicator that assesses a bridge's ability to maintain its structural stability when subjected to loads or other environmental influences [35]. The evaluation of this indicator consists of 3 levels, including (1) no impact on the bridge if 1 component fails, (2) affecting specific parts of the bridge, and (3) impacting the entire bridge.

2.3.2. Traffic safety

This indicator evaluates the extent to which a bridge provides traffic safety for its users. The evaluation of traffic safety considers 4 levels of impact on the environment [36], including (1) no impact on traffic flow, (2) restricting speed limits, (3) causing traffic diversion due to congestion, and (4) resulting in road closures.

2.3.3. Durability

Durability assesses how long a bridge can withstand loads and environmental influences without requiring intensive repairs or maintenance [37,38]. Durability is heavily influenced by the materials used and the quality of construction. The evaluation of this indicator considers 2 levels of impact, including (1) no impact on the durability of other components and (2) affecting the durability of other components.

2.3.4. Bridge general condition

This indicator evaluates the general condition of the bridge, including its performance and structural health. Assessing the general condition of the bridge helps understand how well the bridge functions in the context of maintenance [39,40].

2.3.5. Availability indicator

The availability indicator assesses the accessibility of the bridge, specifically how often the bridge can be accessed without disruptions [41]. This indicator operates at the system level and provides an overview of the bridge's performance when maintenance and repair activities may affect its availability to users.

2.3.6. Bridge importance

This indicator assesses the role of the bridge within the transportation system [42]. At the network level, the importance of a bridge is determined by 5 criteria such as road category, average daily traffic (ADT), detour distance, the longest span of the bridge, and the total length of the bridge.

2.4. Hypotheses development

A QMS consists of a collection of documented procedures and standardized practices designed to ensure that a product's processes meet specific requirements [43]. In the context of maintenance and rehabilitation for bridges, these activities must adhere to set specifications and work standards.

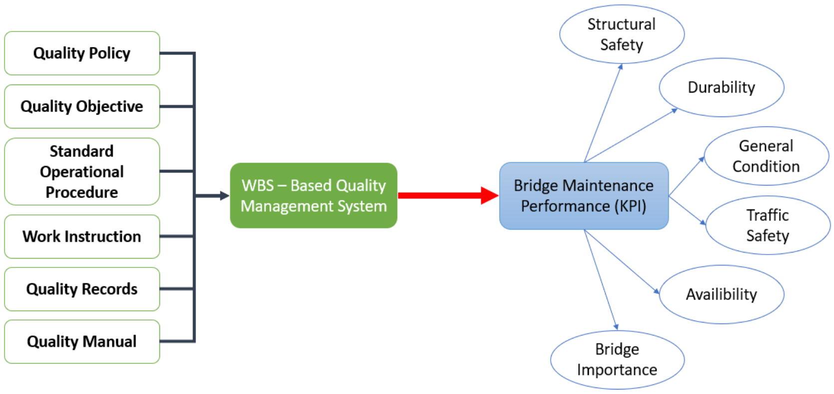

Fig. 1. Framework of WBS-Based QMS.

The conceptual framework (as shown as in fig.1) for this research highlights the relationship between a QMS and maintenance performance. Previous investigations identified challenges in Indonesia's bridge maintenance processes, due to inadequate quality management (Suite, 1995; Cokronegoro, 2010). A well-implemented QMS can address these challenges by ensuring compliance with established specifications and quality standards, improving the performance of maintenance and rehabilitation activities. This research posits that the independent variable, a QMS for concrete bridge maintenance, positively influences the dependent variable, which is the maintenance performance of the bridge. Therefore, the hypothesis formulated from this framework is that the development of a QMS in maintenance and rehabilitation activities will lead to improved performance outcomes.

3. Methodology

3.1. Research design & variable

This research uses a quantitative approach to analyze the relationship between a QMS implementation and bridge maintenance performance in Indonesia. This investigation is divided into 2 stages:

1. A QMS Enhancement: This stage involves designing a QMS specifically for bridge maintenance, integrating elements from existing frameworks and literature to improve maintenance performance.
2. Statistical Analysis: The second stage focuses on evaluating the impact of a QMS on bridge maintenance using statistical methods, such as regression and correlation analysis, to measure performance indicators like efficiency, safety, and sustainability.

Also, there are variables used, as in table 2:

Table 2. Component Variable of WBS-Based Quality Management System.

Code	Variable	Code	Indicators	Reference
X.1	Quality Policy	X.1.1	Clear and documented	ISO 9001:2015
		X.1.2	Easy to understand and can be communicated to all related personnel	
		X.1.3	Compiled based on applicable regulations	
		X.1.4	Focus on the goals of the company or organization	
X.2	Quality Objectives	X.2.1	Can be measured and evaluated periodically	ISO 9001:2015
		X.2.2	Focus on products and customers	
		X.2.3	Compliance with applicable regulations	
		X.2.4	Consistent with established quality policies	
		X.2.5	Communicated and updated periodically	

Code	Variable	Code	Indicators	Reference
X.3	SOP (Standard Operational Procedure)	X.3.1	Clear and easy to understand	Ministerial Regulation of PAN-RB No. 35 of 2012
		X.3.2	Efficient and effective procedures in its implementation	
		X.3.3	Measurable success	
		X.3.4	Dynamic or adaptable to needs	
		X.3.5	User-oriented	
		X.3.6	Comply with applicable legal provisions	
		X.3.7	It can be used as a legal product that is obeyed, implemented, and protects employees from lawsuits	
X.4	Work Instructions	X.4.1	Work instructions are clear and easy to understand	Minister of PUPR No. 4 of 2009 and SNI ISO 9001:2015
		X.4.2	Measurable success	
		X.4.3	Dynamic or adaptable to needs	
		X.4.4	User-oriented	
X.5	Quality Records	X.5.1	Fully documented and organized	Minister of PUPR No. 4 of 2009 and SNI ISO 9001:2015
		X.5.2	Compliance with applicable regulations	
		X.5.3	Recorded in an actual (timely) and relevant manner (in accordance with procedures)	
		X.5.4	Clear and easy-to-identify	
X.6	Quality Manual	X.6.1	Easy to understand and can be communicated to all related personnel	Minister of PUPR No. 4 of 2009 and ISO 9001:2015
		X.6.2	Oriented to applicable regulations	
		X.6.3	Can be used as a legal product that is obeyed, and applied by all parties	
Y	Maintenance Performance	Y1	Structural safety	(Ivankovic, A. et al, 2021)
		Y2	Traffic safety	(Ivankovic, A. et al, 2021)
		Y3	Durability	(Ivankovic, A. et al, 2021)
		Y4	General condition of the bridge	(Ivankovic, A. et al, 2021)
		Y5	Availability of bridge performance	(Ivankovic, A. et al, 2021)
		Y6	The importance of the bridge	(Ivankovic, A. et al, 2021)

3.2. Population and sample

This research is conducted in 2 stages, each with specific population criteria:

1. Stage 1: Delphi Method (Expert Validation):
   - Participants: Experts with at least 5 years of experience in bridge maintenance and a QMS principles.
   - Sample Size: A minimum of 5 experts, selected for their expertise to refine the QMS framework.
2. Stage 2: Survey of Respondents:
   - Participants: Professionals with 1 to 3 years of civil engineering experience, particularly in bridge maintenance.
   - Sample Size: A minimum of 15 respondents, using purposive sampling to ensure participants are knowledgeable in both bridge maintenance and QMS.

3.3. Data collection and analysis methods

Data collection and analysis are structured as follows:

1. Stage 1: Delphi Method (Expert Opinion Collection):
   - Data Collection: Structured questionnaires were sent to experts to gather a valuable understanding of QMS implementation in bridge maintenance.
   - Analysis: Thematic analysis to identify key trends and themes from expert responses.
2. Stage 2: Survey of Respondents (Quantitative Data Collection):
   - Data Collection: A structured survey with closed-ended Likert scale questions and open-ended questions to assess a QMS and maintenance performance.
   - Analysis: Statistical methods (e.g., regression, correlation) will be used to explore the relationship between QMS and maintenance performance, with thematic analysis of open-ended responses for qualitative insights.

4. Results & discussion

4.1. Enhanced quality management system

The development of a QMS for bridge maintenance and repair is in line with the framework set by the Ministry of Public Works and Housing (PUPR) Regulation No. 4 of 2009. A QMS is structured across 6 validated components, based on research questions RQ1 to RQ10, ensuring alignment with the standards for concrete bridge maintenance. The QMS document adheres to the Project Management System Report format used by the Ministry of Public Works of Indonesia, consisting of 5 chapters:

1. Chapter 1: Introduction
   This chapter provides the background, objectives, and scope of the QMS for concrete bridge maintenance and repair.
2. Chapter 2: Literature Review
   This chapter explains the general principles of Quality Management Systems and their relevance to the construction and maintenance of bridges.
3. Chapter 3: Quality Manual
   This section outlines the quality policy, objectives, organizational structure, and responsibilities. It includes the process flowchart and a list of relevant documentation for bridge maintenance work.
4. Chapter 4: Procedures, Duties, and Responsibilities
   This chapter details the SOPs for the 10 main stages of concrete bridge maintenance and repair.
5. Chapter 5: Work Instructions, Checklists, and Quality Records
   It provides WI, checklists, and quality records for the 10 key stages of bridge maintenance.
6. A QMS was validated through expert feedback obtained from 5 professionals with extensive experience in bridge maintenance and repair. This feedback was collected using questionnaires and interviews. These experts included directors, academics, and quality managers with years of experience ranging from 10 to 45 years. The validation process used an ordinal scale from 1 (not suitable) to 5 (highly suitable), resulting in the following conclusions:

   1. Format and Presentation: The average score for the document's format and presentation was 4.0 and 4.7, indicating that the format was appropriate.
   2. Content and Component Suitability: a QMS components and the general content received scores between 4.3 and 5.0, showing that the content is highly relevant to bridge maintenance work.

3. Performance Indicators and Effectiveness: The system's effectiveness in improving maintenance performance was rated between 4.3 and 4.7, confirming that a QMS is effective and can improve the structural safety, traffic capacity, durability, and overall condition of bridges.

A QMS was designed to improve structural integrity, traffic management, and durability of bridges, with a WBS tailored to bridge maintenance. The quality policy adheres to national maintenance standards and allows for periodic updates. Expert validation confirmed that a QMS is well-suited for bridge maintenance work and effectively improves maintenance performance.

4.2. Bridge performance evaluation

This section discusses the relationship between a QMS for concrete bridge maintenance and repair (variable X) and bridge maintenance performance (variable Y). The content analysis focused on the indicators for variable X to variable Y (Detail calculation attached on appendix B) Additionally, an assessment was conducted to determine the influence of both variables in improving bridge maintenance and repair performance.

4.2.1. Data sufficiency test

The data sufficiency test concluded that a sample of 33 respondents was sufficient to represent the findings of this research. The minimum sample size requirement based on statistical analysis was achieved, as indicated by the sample size adequacy score (Kaiser-Meyer-Olkin measure = 0.803), which is well above the acceptable threshold of 0.5.

4.2.2. Homogeneity test

The homogeneity test grouped respondents into 4 categories, including company, position, work experience, and education. The results indicated that there were no significant differences in understanding or perception among respondents from different companies ($p = 0.578$), positions ($p = 0.427$), or educational backgrounds ($p = 0.639$). However, differences in perceptions were found among respondents based on work experience, with p-values less than 0.05 ($p = 0.041$), indicating a statistically significant divergence in perceptions regarding QMS and maintenance performance.

4.2.3. Validity test

In this research, the validity test confirmed that all indicators for both variables X and Y were valid. Each of the indicators showed a factor loading greater than 0.7 (ranging from 0.711 to 0.893), which exceeds the minimum acceptable threshold of 0.5, thereby confirming the validity of the measurement model.

4.2.4. Reliability test

The reliability test showed that the Cronbach's Alpha value was 0.955, indicating that the questionnaire used was highly reliable and could be trusted to produce consistent results. All constructs exhibited strong internal consistency, with Cronbach's Alpha scores for individual constructs ranging from 0.890 to 0.967, well above the recommended threshold of 0.7.

4.2.5. Correlation Test

The correlation test measured the relationship between a QMS and bridge maintenance performance (as shown as in table 3). The Pearson correlation coefficient between variable X (QMS) and variable Y (maintenance performance) was 0.768, indicating a strong positive correlation between the 2 variables.

This strong correlation supports the hypothesis that a QMS positively influences bridge maintenance performance.

Table 3. Correlation Test Results.

VARIABLE	Y.1.1	Y.1.2	Y.1.3	Y.1.4	Y.1.5	Y.1.6
X.1.1	0,324	.354*	0,165	.424*	0,087	0,260
X.1.2	.483**	.353*	0,172	.422*	0,212	.439*
X.1.3	0,335	.518**	0,201	.473**	0,269	0,338
X.1.4	0,293	0,322	-0,084	0,246	.484**	0,130
X.2.1	.364*	0,300	0,111	0,275	0,340	0,312
X.2.2	.374*	.408*	0,132	0,315	.409*	.354*
X.2.3	0,289	.358*	0,031	.396*	0,209	.390*
X.2.4	0,297	.444**	0,214	.406*	.388*	.452**
X.2.5	0,235	0,334	0,097	0,305	0,231	.476**
X.3.1	0,286	.360*	0,160	0,329	0,142	0,270
X.3.2	.575**	.538**	0,212	.493**	0,219	.522**
X.3.3	0,187	0,100	0,138	0,092	0,163	0,233
X.3.4	.520**	0,311	0,040	0,284	.451**	.627**
X.3.5	.467**	.482**	0,181	0,289	0,341	.651**
X.3.6	.353*	.373*	0,240	.413*	0,255	.477**
X.3.7	.496**	.439*	-0,057	0,338	.397*	0,329
X.4.1	.400*	.486**	.385*	.531**	.393*	.388*
X.4.2	.457**	0,289	0,300	.347*	.363*	.365*
X.4.3	.409*	.403*	0,149	0,300	.456**	.482**
X.4.4	0,253	.521**	-0,065	0,217	0,269	.402*
X.5.1	0,286	.473**	.368*	.433*	.418*	.366*
X.5.2	0,224	.414*	0,244	.379*	0,111	0,146
X.5.3	0,260	.496**	0,285	.453**	0,253	0,214
X.5.4	.490**	.607**	.423*	.472**	0,277	0,331
X.6.1	0,104	0,217	0,097	0,199	0,129	.609**
X.6.2	0,333	0,279	0,092	0,255	0,121	.761**
X.6.3	0,199	0,093	-0,147	0,152	0,108	.729**

4.2.6. Linear regression analysis

Linear regression analysis showed that a QMS significantly influenced certain performance indicators of bridge maintenance.

- The variable Y.1.1 (Structural Safety) was significantly influenced by the development of a QMS, with a standardized beta coefficient (β) of 0.741 and an R-squared value of 0.549 ($p < 0.001$), explaining 54.9% of the variance in structural safety. This shows that improving the QMS has a substantial effect on the structural integrity of bridges.
- The variable Y.1.6 (Bridge Importance) was also significantly influenced by a QMS, with a standardized beta coefficient (β) of 0.774 and an R-squared value of 0.599 ($p < 0.001$), accounting for 59.9% of the variance. This underscores the important role of the QMS in maintaining bridges of high importance.

From these findings, the hypothesis stated in subsection 2.4 (H1) is accepted. This research confirms that the development of a QMS (variable X) for concrete bridge maintenance and repair has a significant positive effect on bridge maintenance performance (variable Y). This shows the importance of implementing a robust QMS to improve both the safety and overall performance of bridge maintenance efforts.

5. Conclusion

This research evaluated the impact of a QMS on the performance of concrete bridge maintenance and repair in Indonesia. The analysis demonstrated that a well-designed QMS significantly enhances key performance indicators, particularly structural safety and operational importance. The results showed that QMS improvements accounted for 54.9% of the variance in structural safety and 59.9% in bridge importance, highlighting its critical role in ensuring both the safety and prioritization of maintenance activities. These findings underline the practical benefits of implementing a robust QMS, including more effective inspections, timely interventions, and improved organizational efficiency in bridge maintenance. This study reinforces the necessity of adopting comprehensive quality management practices to support the long-term reliability and safety of Indonesia's bridge infrastructure.

In terms of research reliability, the instrument used for data collection demonstrated high consistency, with a Cronbach's Alpha value of 0.955, confirming that the results are dependable and repeatable. Additionally, the validity of the indicators for both QMS frameworks and bridge performance was verified, ensuring robust and reliable data. These findings highlight the strength of the research design in providing an accurate and valuable understanding of the relationship between QMS frameworks and bridge maintenance performance. The research also found that respondents' perceptions were largely homogeneous across different groups based on company, position, and education, reflecting a consistent understanding of QMS frameworks within the industry. However, significant differences emerged among respondents with varying levels of work experience, with more experienced professionals offering distinct perspectives on the operational prioritization of bridges. This underscores the influence of practical experience in shaping views on the effectiveness of quality management systems in bridge construction and maintenance.

A strong correlation ($r = 0.768$) was identified between a QMS and overall bridge maintenance performance, further reinforcing the idea that a well-implemented QMS leads to better maintenance results. This finding supports the research hypothesis (H1) and underscores the importance of investing in quality management systems to enhance the durability, safety, and operational efficiency of bridges. In conclusion, this research confirmed that a well-developed QMS significantly improved bridge maintenance performance, both in terms of structural safety and operational importance. The practical implications of this research suggest that both government agencies and private companies should prioritize the development of comprehensive QMS frameworks for bridge maintenance. Additionally, future research should explore other factors that may further enhance the impact of a QMS on maintenance performance. By focusing on continuous improvement in quality management practices, the bridge maintenance sector can ensure safer, more reliable infrastructure throughout Indonesia.

Acknowledgement

The author would like to thank the financial support provided by the University of Indonesia through PMDSU Funding BIMA with the contract number: NKB-974/UN2.RST/HKP.05.00/2024 managed by the faculty of engineering Universitas Indonesia from ministry of higher education and research of Indonesia.

Funding

The author would like to thank the financial support provided by the University of Indonesia through PMDSU Funding BIMA with the contract number: NKB-974/UN2.RST/HKP.05.00/2024 managed by the faculty of engineering Universitas Indonesia from ministry of higher education and research of Indonesia.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors contribution statement

Naufal Budi Laksono: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Software; Visualization; Roles/Writing – original draft.

Fairus Kanza Januar Mashito: Data curation; Formal analysis; Investigation; Software; Visualization; Roles/Writing – original draft.

Yusuf Latief: Conceptualization; Supervision; Validation; Writing – review & editing.

Bambang Trigunarsyah: Methodology; Validation; Writing – review & editing.

References

[1] Wang YW, Ni YQ, Wang SM. Structural health monitoring of railway bridges using innovative sensing technologies and machine learning algorithms: A concise review. Intell Transp … 2022. https://doi.org/10.1093/iti/liac009/6732506.

[2] Capacci L, Biondini F, Frangopol DM. Resilience of aging structures and infrastructure systems with emphasis on seismic resilience of bridges and road networks: Review. Resilient Cities Struct 2022;1:23–41. https://doi.org/10.1016/j.rcns.2022.05.001.

[3] C. Crawford K. Perspective chapter: Bridge deterioration and failures. In: Ravindran G, Mahesh V, Kassem MM, editors. Fail. Anal. - Struct. Heal. Monit. Struct. Infrastruct. Components, London, England: IntechOpen; 2023.

[4] Banerjee S, Vishwanath BS, Devendiran DK. Multihazard resilience of highway bridges and bridge networks: a review. Struct Infrastruct Eng Maint Manag Life-Cycle Des Perform 2019;15:1694–714. https://doi.org/10.1080/15732479.2019.1648526.

[5] Ali T. Resilient Infrastructure: Adapting Civil Engineering to Climate Change and Natural Disasters. Lib J Lang Lit Rev 2023.

[6] Oreto C, Biancardo SA, Abbondati F, Veropalumbo R. Leveraging infrastructure BIM for life-cycle-based sustainable road pavement management. Mater 2023;16:1047. https://doi.org/10.3390/ma16031047.

[7] Zhao X, Yang H, Yao Y, Qi H, Guo M, Su Y. Factors affecting traffic risks on bridge sections of freeways based on partial dependence plots. Physica A 2022;598:127343. https://doi.org/10.1016/j.physa.2022.127343.

[8] Tang D, Huang M. The sustainable development of bridges in China: Collapse cause analysis, existing management dilemmas and potential solutions. Buildings 2024;14:419. https://doi.org/10.3390/buildings14020419.

[9] Jumlah Jembatan Nasional 2025.

[10] De Bartolomeo D, Renzi E, Tamasi G, Palermo G, Nucci F Di. The Italian Risk-Based approach for the development of an Integrated Safety Management System for Road Infrastructures and its Relations with innovative guidelines on the risk management of existing bridges. Transp Res Procedia 2023;69:886–93. https://doi.org/10.1016/j.trpro.2023.02.249.

[11] Puspitasari S, Harahap S, Astuti P. A Critical Review of Bridge Management System in Indonesia, 2022, p. 381–9.

[12] Hari WA, Tiong I. Forensic engineering analysis of building structures in Indonesia: a case study of the collapse of the Mahakam II Kutai Kartanegara bridge in East Borneo. Russ J Agric Socio … 2019.

[13] Zhang Y, Zhu Y, Yeseta M, Meng D, Shao X, Dang Q, et al. Flexural behaviors and capacity prediction on damaged reinforcement concrete (RC) bridge deck strengthened by ultra-high performance concrete

(UHPC) layer. Constr Build Mater 2019;215:347–59. https://doi.org/10.1016/j.conbuildmat.2019.04.229.

[14] R I, A W, I M. Development of bridge inspection quality assurance for sustainable bridge management system in Indonesia. Pros KRTJ HPJI 2023;16:1–14. https://doi.org/10.58674/phpji.v16i1.319.

[15] Davila Delgado JM, Butler LJ, Gibbons N, Brilakis I, Elshafie MZEB, Middleton C. Management of structural monitoring data of bridges using BIM. Proc Inst Civ Eng - Bridg Eng 2017;170:204–18. https://doi.org/10.1680/jbren.16.00013.

[16] Zanini MA, Faleschini F, Casas JR. State-of-research on performance indicators for bridge quality control and management. Front Built Environ 2019;5. https://doi.org/10.3389/fbuil.2019.00022.

[17] Naghavi-Konjin Z, Mortazavi SB, Mahabadi HA, ... Identification of factors that influence occupational accidents in the petroleum industry: A qualitative approach. Work 2020.

[18] Tambare P, Meshram C, Lee C-C, Ramteke RJ, Imoize AL. Performance measurement system and quality management in data-driven Industry 4.0: A review. Sensors (Basel) 2021;22:224. https://doi.org/10.3390/s22010224.

[19] Casas JR, Matos JC. Quality specifications for roadway bridges, standardization at a European level. Risk-based Bridg. Eng., CRC Press; 2019, p. 285–98.

[20] Johnson MB, Bektas BA. Defining Bridge Preservation by Action Type. Transp Res Rec 2013;2360:21–6. https://doi.org/10.3141/2360-03.

[21] Aryanto D, Riantini L, Machfudiyanto RA, Latief Y. Identification Risk Potential Hazard of Railway Project Based on the Work Breakdown Structure to Improve Safety Performance, 2022, p. 641–50.

[22] Machfudiyanto RA, Kim S, Latief Y, Rachmawati TSN, Laksono NB. Analysis of design-for-safety implementation factors in the Indonesian construction industry: A two-staged SEM-artificial neural network approach. Heliyon 2023;9:e21273. https://doi.org/10.1016/j.heliyon.2023.e21273.

[23] Akram MN, Latief Y, Nugroho DB. Development of the Construction Safety Goals and Programs During the Design and Construction Phase for the Audit Process to Improve Construction Safety Performance. Int J Eng Trends Technol 2024;72:71–80. https://doi.org/10.14445/22315381/IJETT-V72I1P108.

[24] Ikarwitaza PA, Riantini LS, Latief Y. Development of dictionary and checklist based on WBS (Work Breakdown Structure) of structure works in stadium construction for safety planning. IOP Conf Ser Earth Environ Sci 2021;794:012045. https://doi.org/10.1088/1755-1315/794/1/012045.

[25] Li Q-F, Zhang P, Fu Y-C. Risk identification for the construction phases of the large bridge based on WBS-RBS. Res J Appl Sci Eng Technol 2013;6:1523–30. https://doi.org/10.19026/rjaset.6.3863.

[26] Strauss A, Mandić Ivanković A, Matos JC, Casas JR, Bourke J, Roper S, et al. Defining a Digital Strategy in a BIM Environment to Manage Existing Reinforced Concrete Bridges in the Context of Italian Regulation. Autom … 2022;15:1217–22. https://doi.org/10.3390/su11174583.

[27] Antony J, Sony M, McDermott O, Jayaraman R, Flynn D. An exploration of organizational readiness factors for Quality 4.0: an intercontinental study and future research directions. Int J Qual Reliab Manag 2023;40:582–606. https://doi.org/10.1108/ijqrm-10-2021-0357.

[28] Hoyle D. ISO 9000 Quality Systems Handbook-updated for the ISO 9001: 2015 standard: Increasing the Quality of an Organization's Outputs. taylorfrancis.com; 2017.

[29] Beyene KG, Nadew S, Ali WG, Gebrehiwot AG, Atsibeha SG. How to write standard operating procedures: values and a practical guide. Int J Drug Regul Aff 2022;10:32–7. https://doi.org/10.22270/ijdra.v10i4.557.

[30] Hubbard DG, Bolles DL, PMP P. PMO Framework and PMO Models for Project Business Management. PM World J 2015.

[31] Giacumo LA, Breman J. Trends and implications of models, frameworks, and approaches used by instructional designers in workplace learning and performance improvement. Perform Improv Q 2021;34:131–70. https://doi.org/10.1002/piq.21349.

[32] Eniola AA, Olorunleke GK, Akintimehin OO, Ojeka JD, Oyetunji B. The impact of organizational culture on total quality management in SMEs in Nigeria. Heliyon 2019;5:e02293. https://doi.org/10.1016/j.heliyon.2019.e02293.

[33] Strauss A, Vidovic A, Zambon I, Dengg F, Tanasic N, ... Performance indicators for roadway bridges. repositorium.sdum.uminho.pt; 2016.

[34] Mandić Ivanković A, Skokandić D, Kušter Marić M, Srbić M. Performance-based ranking of existing road

bridges. Appl Sci 2021;11:4398. https://doi.org/10.3390/app11104398.

[35] Poli F, Bado MF, Verzobio A, Zonta D. Bridge structural safety assessment: a novel solution to uncertainty in the inspection practice. Struct Infrastruct Eng Maint Manag Life-Cycle Des Perform 2023:1–15. https://doi.org/10.1080/15732479.2023.2211956.

[36] Zhou J, Caprani CC, Zhang L. On the structural safety of long-span bridges under traffic loadings caused by maintenance works. Eng Struct 2021;240:112407. https://doi.org/10.1016/j.engstruct.2021.112407.

[37] Nader M, Choi C, Vo N, Sanjines A. Maintenance plan and durability design for the new Samuel De Champlain Bridge. Bridg. Safety, Maintenance, Manag. Life-Cycle, Resil. Sustain., London: CRC Press; 2022, p. 1931–8.

[38] Osmolska MJ, Kanstad T, Hendriks MAN, Hornbostel K, Markeset G. Durability of pretensioned concrete girders in coastal climate bridges: Basis for better maintenance and future design. Struct Concr 2019;20:2256–71. https://doi.org/10.1002/suco.201900144.

[39] Harywijaya W, Afifuddin M, Isya M. PENILAIAN KONDISI JEMBATAN MENGGUNAKAN BRIDGE MANAGEMENT SYSTEM (BMS) DAN BRIDGE CONDITION RATING (BCR). J Arsip Rekayasa Sipil Dan Perenc 2020;3:80–8. https://doi.org/10.24815/jarsp.v3i1.16462.

[40] Juliastuti, Setyandito O, Suangga M, Sulistyono D. The river flow regime assessment model of bridge condition rating for preventive maintenance program. IOP Conf Ser Earth Environ Sci 2018;195:012019. https://doi.org/10.1088/1755-1315/195/1/012019.

[41] Nichols CR, Wright LD, Bainbridge SJ, Cosby A, Hénaff A, Loftis JD, et al. Collaborative science to enhance coastal resilience and adaptation. Front Mar Sci 2019;6. https://doi.org/10.3389/fmars.2019.00404.

[42] Malarich K, Leckrone T, Thompson PD, Gager K, Alampalli S. Integration of AASHTO element data into the New York State Department of Transportation bridge management system: Treatments and project selection. Transp Res Rec 2022;2676:279–88. https://doi.org/10.1177/03611981221086618.

[43] Dronova I. Environmental heterogeneity as a bridge between ecosystem service and visual quality objectives in management, planning and design. Landsc Urban Plan 2017;163:90–106. https://doi.org/10.1016/j.landurbplan.2017.03.005.