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Development of Information System for Concrete Bridges Maintenance Quality Management System Based on Website to Improve Maintenance Performance

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ABSTRACT
In Indonesia, issues related to bridge maintenance and preservation are still frequently encountered, as indicated by the high number of bridges experiencing damage and even structural failure compared to those that remain in good condition. This study aims to develop a quality management system for the maintenance and preservation of concrete bridges by integrating an information system that can effectively manage data and information in a structured manner and facilitate the visualization of bridge conditions and maintenance needs throughout the maintenance phase. The integration of both components within a single information system is expected to enhance the effectiveness and efficiency of bridge maintenance and preservation processes. This research employs a qualitative approach using a case study method on the Bukit Indah Bridge located on the Cinere-Serpong Toll Road. Data collection was conducted through literature studies, document analysis, and field observations. All collected data were validated by experts in the field of road and bridge maintenance, as well as experts in quality management systems and information systems. Further analysis focuses on developing a model that demonstrates the relationship between the implementation of a web-based Quality Management System and the improvement of concrete bridge maintenance and preservation performance. The final outcome of this study is an information system capable of supporting decision-making processes to optimally improve the performance of bridge maintenance and preservation..

Keywords: Quality Management System, Information System, Maintenance, Indonesian Bridge.

INTRODUCTION
Concrete bridges play a strategic role in Indonesia's national transportation network, serving as a link between regions to facilitate the movement of people and the distribution of goods. As an archipelagic country consisting of thousands of large and small islands, the existence of bridge infrastructure is very important to overcome geographical barriers while encouraging economic growth (Ministry of PUPR, 2022). The use of reinforced concrete is also driven by the abundant availability of materials and the more affordable cost of producing concrete than other construction materials such as steel. Therefore, reinforced concrete is an economical and practical solution in the construction of strong and durable bridges, especially in Indonesia. The advantages of reinforced concrete in resisting earthquakes are also an important factor. With Indonesia's geological conditions being among the active plates, the strength of reinforced concrete against earthquakes makes it a reliable solution in bridge construction.

In 2022, Indonesia has a total of 18,990 National Bridges with a total length of 536,585 meters, based on infrastructure statistical data from the Ministry of Public Works and Housing. According to the Directorate General of Highways, in September 2022, as many as 14.48% of the bridge infrastructure was in an unstable condition, with a total of 2,897 units. These unstable conditions include bridges that are severely damaged, critical, or even broken. Only 1% of the total bridges recorded are in good condition. This condition raises concerns about the safety and resilience of national bridge infrastructure in Indonesia. The Director General of Highways, Hedy Rahadian, stated that in the 2023 Strategic Plan, the target for the stability of road and bridge infrastructure is expected to reach 96%. However, with the large budget allocated for road and bridge preservation work in 2023, which is IDR 22.97 trillion, it is predicted that the stability of the roads that can be achieved is only 93.57%.

The unstable condition of bridges, especially bridges that have collapsed, shows a significant increase in number over time. This phenomenon is caused by various conditions that affect the reliability of the bridge structure. One of the main factors causing bridge collapse is the decrease in the quality of construction materials, especially in piles that often experience severe cracks due to excessive loads. Based on data from the Ministry of Public Works and Public Housing, the trend of bridge collapse over the past ten years shows a fluctuating pattern. One striking example is the collapse of the Kutai Kartanegara Bridge in 2011, which became one of the largest infrastructure incidents in Indonesian history. This phenomenon of bridge collapse has a significant impact, which can be felt on three levels: micro, mezzo, and macro.

- Micro Impact: At the micro level, the impact of the bridge collapse is felt directly by individuals or small groups who are in the vicinity of the scene. These impacts include:
- Mezzo Impact: At the mezzo level, the collapse of the bridge has an impact that is felt by the wider community or region. These impacts include:
- Macro Impact: At the macro level, the impact of bridge collapse has a wider scope, up to a national scale, even internationally, depending on the importance of the bridge in the country's transportation and economic network.
- Impact on international reputation: At the global level, the collapse of bridges can affect Indonesia's image and reputation as a country with poorly maintained infrastructure, thereby reducing the attractiveness of foreign investment in the infrastructure and transportation sectors.

Proper maintenance can extend the service life of the bridge and reduce the risk of structural failure, especially on bridges that are often subjected to overload or exposed to extreme environmental conditions. With periodic monitoring and maintenance, potential problems that arise can be identified and corrected more quickly before they impact a more serious collapse. Therefore, the repeated collapse of bridges in various regions underscores the importance of improving maintenance and maintenance performance to maintain the safety, stability, and longevity of bridge infrastructure in Indonesia.

The Quality Management System (SMM) plays a strategic role in maintaining the feasibility of the bridge's function through periodic inspections and condition evaluations. These inspections allow for early identification of maintenance or repair needs, so that necessary action can be taken before the problem becomes more serious (Kumalasari & Sumargo, 2020). In the context of bridge maintenance, SMM has an important role in organizing, directing, and controlling all activities of the construction implementation process that takes place in an integrated manner in each work unit, implementing unit, and service provider that plays a role in the project. This aims to ensure that the quality standards that have been set can be achieved consistently in every stage of work.
Quality management not only functions as a technical indicator, but is also a measure of performance that must be accounted for in the implementation of infrastructure development. Improving the quality of quality management needs to be carried out in a sustainable manner to achieve optimal results and support infrastructure sustainability (Marpaung et al., 2020). Therefore, further development of the Quality Management System (SMM) in the maintenance and maintenance work of concrete bridges is urgently needed. This system will improve the

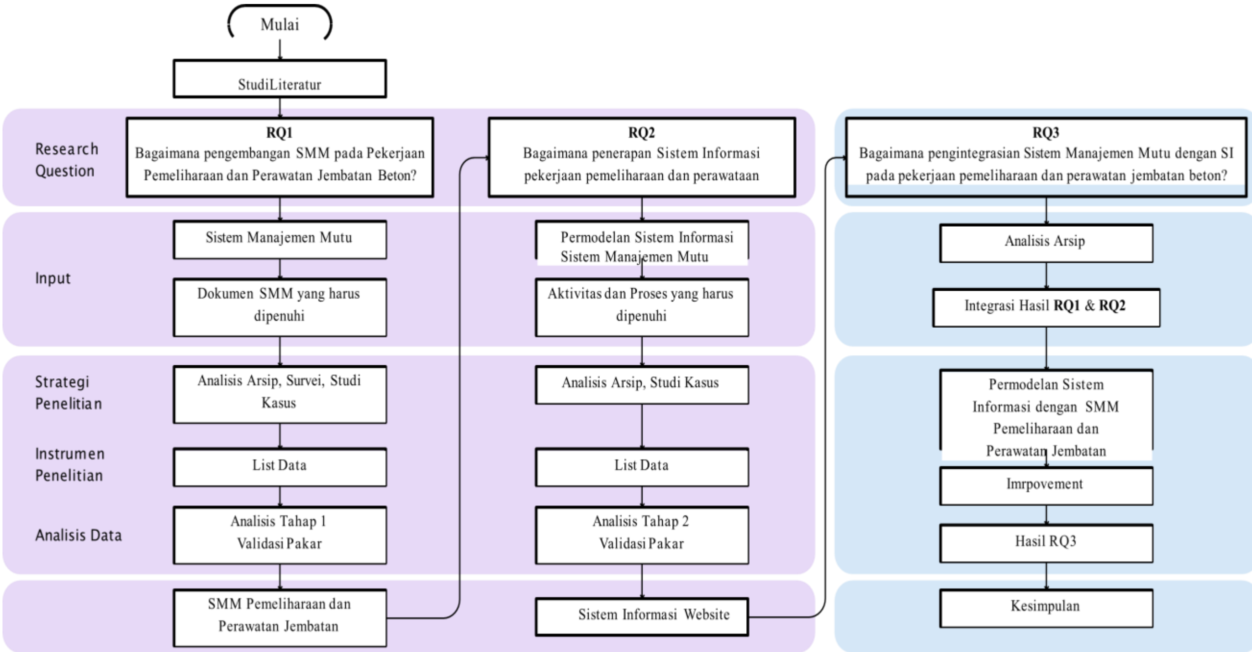
effectiveness of quality control and maintenance performance, so that the bridge can continue to operate safely and efficiently throughout its service life.

However, bridge maintenance and inspection activities that still rely on manual methods, despite the implementation of a Quality Management System (SMM), are still not effective enough due to their low efficiency level (Kaewunruen et al., 2021). This is further exacerbated by the increasing risk of damage and defects to the bridge every day. In this context, the application of Knowledge Base has been widely used to address challenges related to interoperability and information flow (Salzano et al., 2023).

The information system operates using a vast data server network interconnected within a unified system. Each server functions as a combination of information blocks organized by size and holds significant strategic value for the various parties involved. The information system platform itself stores a variable database, which is open to data exchange processes, analysis based on adopted regulations, and the gradual transmission of information—seemingly in a continuous update mode—on various topics or subjects. The purpose of this process is to provide an objective evaluation of existing realities, share experiences, and offer tools for monitoring and controlling partner activities within specific settings (for example, when a project is monitored by multiple departments, where the responsibilities of each directly affect the efficiency of others).
Departments or units within an organization often face difficulties in accessing information regarding each other's operations. In many cases, documentation related to processes or decisions is still recorded on paper, which makes the organization less stable and hinders effective decision-making procedures. Therefore, it is evident that information systems play a crucial role in structuring human activities in a more organized way, transforming individually driven approaches into system-based actions.

RESEARCH METHODS

This research will be conducted using a quantitative approach, which is a systematic and structured type of scientific research that focuses on observing specific parts of a phenomenon and the relationships between its components. Quantitative research typically involves collecting a predetermined amount of data from a defined population to generate generalizable findings (Ahyar, Andriani, & Sukmana, 2020). The emphasis lies in the analysis of numerical data, processed through appropriate statistical methods to produce valid and accountable conclusions. The selection of research strategy is determined based on the research questions, guiding the research process and the choice of relevant data collection methods. In this study, two main strategies will be employed. First, the case study approach will be used to facilitate theoretical model development and provide an in-depth understanding of the audit process in design-build contract systems for high-rise buildings, including risk analysis, knowledge construction, and the development of a knowledge management information system. As defined by Basrowi & Suwandi (2012) and Yin (2002), case studies encompass the overall research strategy including design, data collection techniques, and analytical approaches. Second, the survey method will be applied to gather data from qualified respondents such as construction safety committee members and personnel involved in high-rise building projects under design-build contracts. Data will be collected using questionnaires and structured interviews to systematically observe and record phenomena relevant to the research (Hadi, 2015).



In this research, several types of variables are identified. Independent variables (X1 and X2), namely the Quality Management System (SMM) and Information System (IS), are considered the factors that influence or cause changes in the dependent variable. The dependent variable (Y) is the maintenance work of concrete bridges in Indonesia, which is the primary focus of the study and is expected to change as a result of the changes in the independent variables. The moderating variable affects the strength or direction of the relationship between the independent and dependent variables, potentially enhancing or weakening the connection between the two. The intervening variable theoretically explains the relationship between the independent and dependent variables, providing insights into how the independent variables influence the dependent variable. For instance, employee motivation could serve as an intervening variable in a study on the impact of training on employee performance. Lastly, the control variables are kept constant by the researcher to ensure that the influence of independent variables on the dependent variable is not affected by other unexamined factors, thus ensuring more accurate results. In this study, controlling for factors such as background variables ensures that the effects of SMM and IS on bridge maintenance performance are not biased by unrelated influences. Through this classification and understanding of variables, this research aims to provide deeper insights into the factors affecting the performance of concrete bridge maintenance.

In this study, expert validation will be conducted in three stages using questionnaires, with each stage having a specific purpose to ensure that all aspects of the research instrument are tested and aligned with the necessary standards. These validation stages are designed to ensure that the research instrument not only meets academic criteria but is also practical and applicable within the studied context. The first validation stage aims to validate the Quality Management System (SMM) developed for the maintenance and repair of concrete bridges. At this stage, five experts with a minimum of ten years of experience in the field of bridges will review and provide feedback on the instrument's suitability and completeness, ensuring that it accurately measures the intended variables. The second validation stage seeks validation for the results of the data analysis and the recommended Knowledge Management (Knowledge Base) development model, which includes variables and activities for the maintenance and repair of concrete bridges. This validation will ensure that the analysis results and the proposed model are accurate and can be effectively applied in the research context. The third validation stage aims to validate the integration between the Quality Management System and Knowledge Management developed for the maintenance and repair of concrete bridges. This validation will confirm that the integration functions effectively, allowing both systems to work synergistically to enhance the quality of bridge maintenance and repair.

The researcher utilizes two different types of data to obtain comprehensive results: primary and secondary data. Primary data is defined as the main source of data collected directly from the objects of the study, where the information obtained is original and not mediated. Sugiyono (2019) explains that primary data is data that is directly provided by the respondents or subjects of the study to the data collector in the field. In other words, primary data is collected through direct interaction or observation of relevant sources of information pertaining to the research problem being examined. On the other hand, secondary data is supportive data that complements or strengthens primary data. This data is not obtained directly from the research objects but through indirect sources such as documents, written reports, publications, or from other parties who have previously collected the data. Secondary data may include relevant government regulations, reference books, published journal articles, as well as theses or other scholarly works related to the research topic. In the context of this research, primary data collection is carried out through interviews designed in the form of questionnaires. These interviews involve experts in the relevant fields and other research subjects to gather their responses, perceptions, and evaluations of the variables being studied. Meanwhile, secondary data collection is conducted by reviewing various literature sources, such as official regulations, reference books, scientific articles published in journals, and other relevant documents to support the analysis and discussion in this study. All data collection processes, both primary and secondary, are carried out through systematic stages, which will be explained further in the following sections. These stages are designed to ensure that the data obtained has adequate validity and reliability to support credible and scientifically accountable research results.

The researcher uses the Delphi analysis method as the primary approach to obtain validation and consensus from experts. The Delphi method is a decision-making technique that involves the structured and gradual participation of a number of experts in the relevant field. A key feature of this method is that the experts do not meet directly, and each response provided by the experts is kept confidential (anonymous). This aims to minimize the potential for undesirable social influences, such as the domination of opinions or group pressure, allowing each expert to offer objective and independent views. In the initial stage, known as the first iteration, the researcher collects all the responses from the experts. These responses are then analyzed and summarized into a structured report, which is sent back to all the involved experts, giving them the opportunity to review, evaluate, and, if necessary, revise or change their initial opinions based on the perspectives of other experts. This process is repeated in multiple rounds (iterations) until a point is reached where the experts achieve a consensus or agreement on the issue being studied. Through this systematic Delphi approach, the research is expected to reflect a collective, objective viewpoint from competent experts. The final results of the Delphi analysis will be presented in a report summarizing all findings, opinions, and the consensus agreed upon by the experts participating in the study. The Delphi method has several advantages and limitations that should be considered in its application. In a research study, the choice of method is based on considerations relevant to the study's objectives and context. The benefits of the Delphi method include: (a) being effective when available information is limited or when understanding of the topic is low, (b) facilitating predictions or forecasts of future conditions, (c) allowing for the development of flexible research instruments that can be gradually adapted, (d) providing valuable feedback to respondents, enhancing reliability in fact and data verification, (e) enabling broader studies and obtaining comprehensive views on the research topic, (f) being suitable for reaching populations dispersed across wide geographical areas, and (g) being applicable when face-to-face interaction is not feasible. However, the Delphi method also has limitations, such as (a) the potential for varying interpretations due to differences in questionnaire formats across rounds, (b) the results being heavily influenced by the imagination and views of the participating experts, (c) the possibility of bias in communication between participants, and (d) the process requiring substantial costs and time.

RESULTS AND DISCUSSION

Information System Data Collection of Bridge Maintenance Quality Management System

In the first Research Question (RQ), which is to identify the components in the Quality Management System (SMM) for concrete bridge maintenance and maintenance work, secondary data was collected through a documentation study of the Regulation of the Minister of Public Works and Public Housing (PUPR) No. 4 of 2009 concerning the Quality Management System of the Department of Public Works. The regulation serves as a reference in the implementation of quality management which includes the implementation, maintenance, control, and continuous improvement efforts in order to achieve optimal performance in accordance with the principles of the documented Quality Management System.

Quality Management System Expert Data

After conducting an archive analysis, validation is carried out to experts who have education of at least S1 and at least 10 years of experience in the field of bridge maintenance and maintenance by distributing questionnaires. The questionnaire aims to obtain approval and input on the 6 components of the Quality Management System (SMM). In addition, the interview method is also carried out to equalize the perception between the author and experts regarding the content of the questionnaire so that the filling out of the questionnaire can run well and appropriately. Table 4.1 is an expert profile for RQ1 validation.

All experts agree on the components that will be applied in the Quality Management System (SMM) for the maintenance and maintenance of concrete bridges. There are several notes provided by experts related to the SMM component when filling out the questionnaire. Every component, from the quality policy to the quality manual, is very important in the implementation of concrete bridge maintenance and maintenance work to ensure that every work carried out has a good final result (output) in accordance with applicable references and criteria. Therefore, it was decided that the six components must be listed in the Quality Management System (SMM).

Information System Data Development

Based on the components of the Quality Management System (SMM) that have been validated by experts, it can be concluded that there are 6 components that will be applied in the Quality Management System (SMM) for the maintenance and maintenance of concrete bridges, which are as follows:

1. Quality Policy
2. Quality Manual

3. Quality Objectives
4. Quality Procedures
5. Implementation Instructions and Work Instructions
6. Quality Record/Proof of Work

Quality Policy Data Analysis

At this stage, experts validate each concrete bridge maintenance and maintenance quality policy using a questionnaire. Each expert is asked to provide a "yes" or "no" response to each policy contained in the questionnaire and notes or comments as needed. The questionnaire was validated to evaluate the suitability between the quality policy obtained from the results of the archive analysis and the maintenance and maintenance work of the concrete bridge. All experts agree on 3 quality policies that will be applied to the maintenance and maintenance work of concrete bridges. There are several notes and inputs provided by experts related to quality policy when filling out the questionnaire. The quality policy prepared is related to customer needs, regulations, in accordance with implementation, and technological developments in the maintenance and maintenance of concrete bridges. This is of course in accordance with the requirements for determining quality policies in SNI ISO 9001:2015 where the quality policy must be in accordance with the goals and conditions of the organization or customers, meet the applicable requirements, and continuously improve the Quality Management System. In addition, according to expert 3, awareness and competence from workers are also needed so that the Quality Management System can run well so that a quality policy related to this matter is needed.

Results of Quality Policy Data Analysis

Based on the policies that have been validated and input by experts, it can be concluded that there are 4 quality policies applied to concrete bridge maintenance and maintenance work, which are as follows:

1. Committed to meeting the interests and satisfaction of customers by providing high-quality service that is reflected through zero complaints.
2. Committed to complying with applicable regulations and requirements so that the implementation of the Quality Management System can run effectively and efficiently.
3. Committed to improving quality and sustainable innovation through innovation culture by providing improvements to work processes related to the Quality Management System.
4. Committed to increasing the awareness and competence of employees and workers in order to be able to implement the Quality Management System in a correct, safe, and environmentally friendly manner.

The four quality policies that have been prepared are related to customer needs, regulations, in accordance with implementation, awareness and competence of workers, as well as technological developments in the maintenance and maintenance of concrete bridges. This is in accordance with the requirements for determining quality policies in SNI ISO 9001:2015 where quality policies must be in accordance with the goals and conditions of the organization or customers, meet applicable requirements, and continuous improvement of the Quality Management System so that these policies can be a commitment for a company in the implementation of the Quality Management System.

Quality Goals in the Quality Management System

To determine the quality of concrete bridge maintenance and maintenance work targets, secondary data was collected in the form of archival analysis from two documents, which are as follows:

1. Regulation of the Minister of Public Works and Public Housing (PUPR) No. 4 of 2009 concerning the Quality Management System of the Department of Public Works.
2. Manual of Integrated Management System (Quality, Occupational Safety and Health, and Environment) of the Ministry of PUPR Directorate General of Highways in 2016.

3.SNI ISO 9001:2015 on Quality Management System – Requirements

The two documents, Ministerial Regulations and SNI, discuss how to prepare the correct quality targets, which are consistent with quality policies, relevant, measurable and monitorable. Meanwhile, in the Integrated Management System Manual document, there are quality goals used by the Directorate General of Highways. Based on the three documents, 2 quality goals were formulated that will be applied to concrete maintenance and maintenance work, namely:

1. Ensuring reliable and decent bridge maintenance and maintenance services in accordance with applicable quality policies.
2. Achieve the goal without accidents or zero accidents.

Quality Target Data Analysis

At this stage, experts validate each quality target of concrete bridge maintenance and maintenance work using a questionnaire. Each expert was asked to provide a response of "yes" or "no" to each of the objectives contained in the questionnaire and notes or comments if necessary. The questionnaire was validated to evaluate the suitability between the quality goals obtained from the archival analysis and the maintenance and maintenance work of the concrete bridge. All experts agree on 2 quality goals that will be applied to the maintenance and maintenance work of the concrete bridge. There are several notes and inputs provided by experts regarding quality goals when filling out the questionnaire. Expert 2 and Expert 3 provide suggestions on quality goals that can be applied to concrete bridge maintenance and maintenance work. Both suggestions meet the requirements for quality goals because they are consistent with the quality policy that has been made and can be measured so that the suggestions can be accepted and the quality goals implemented increase to 4 goals. In addition, Expert 4 provided input regarding the language order used so that sentence adjustments were made so that all parties could understand it and could avoid misunderstandings.

Data Analysis

At this stage, experts validate the Work Breakdown Structure of concrete bridge maintenance and maintenance work from level 1 to level 5 using a questionnaire. Each expert is asked to provide a response in the form of "appropriate" or "not appropriate" at each level of the WORK BREAKDOWN STRUCTURE in the questionnaire and notes or comments if necessary. The questionnaire was validated to evaluate the suitability between the Work Breakdown Structure obtained from the results of descriptive analysis and the maintenance and maintenance work of the concrete bridge. The results of the validation of all experts are listed in Appendix 1A for the upper structure and Appendix 1B for the lower structure.

Based on the results of expert validation in Attachments 1A and 1B, it can be seen that some experts feel unfamiliar with the terms from the cluster contained in the Work Breakdown Structure level 4. There are several notes and inputs provided by experts related to the Work Breakdown Structure when filling out the questionnaire as seen in Table 4.1.

Table 4.1 Notes and Expert Input on Validation

Expert Code Notes and Feedback
P1 Provide input to increase the activity of adding elements to the pillar foundation cluster, foundation connections and others, as well as strengthening the foundation.
P2 •Less familiar with the terms sleeper slab and apron clusters.
•Special inspection activities are not required on sidewalks and kerbs.
P3 Less familiar with the terms sleeper slab cluster, girder reinforcement, and apron.

Expert 2 and Expert 3 are less familiar with the terms sleeper slab clusters located in the Work Breakdown Structure code 1.1.1.4, the girder reinforcement located in the Work Breakdown Structure code 1.2.1.3, and the apron located in the Work Breakdown Structure code 1.4.4.4. In addition, Expert 2 also provided input related to special inspection activities on the sidewalk and kerb cluster located in the Work Breakdown Structure code 1.2.4.2.4. However, it can be seen that the other three experts stated that the Work Breakdown Structure standard for the maintenance and maintenance of the validated concrete bridge was appropriate, so it was decided that the three main clusters were still included in the Work Breakdown Structure level 4 and the special inspection activities for the sidewalk and kerb clusters were still included in the Work Breakdown Structure level 5. As for input from Expert 1 (P1), input related to the activities of adding elements to the pile foundation cluster, foundation connections and others, as well as strengthening the foundation, the addition of elements to the cluster will be carried out at Work Breakdown Structure level 5, precisely in the Work Breakdown Structure code 1.1.1.1.9 for the pile foundation, the Work Breakdown Structure code 1.1.1.5.9 for foundation connections and others, and Work Breakdown Structure code 1.1.1.6.9 for foundation reinforcement.

Based on the *Work Breakdown Structure standards* that have been validated, it is known that the implementation of concrete bridge maintenance and maintenance consists of 3 main stages, namely the stages of inspection, maintenance, and maintenance so that it requires references related to the 3 main stages. The first and fifth documents are used as a reference for the examination stage, the second and third documents are used as a reference for the maintenance stage, and the fourth document is used as a reference for the treatment or rehabilitation stage. And finally, the sixth document is used as a reference for the Standard Operating Procedure (SOP) format.

No.	Kegiatan	Pelaksana				Mutu Baku			Keterangan
		Kabid	Kasubid	Analis	Asdep	Kelengkapan	Waktu	Output	
1.	Menugaskan Kasubid untuk mempersiapkan konsep laporan konsinyering					Agenda Kerja	15 menit	Disposisi	
2.	Memerintahkan analis untuk mengumpulkan bahan laporan konsinyering					Disposisi	15 menit	Disposisi	
3.	Mengumpulkan dan menyerahkan bahan konsinyering kepada Kasubid					Disposisi	1 hari	Bahan Laporan, Disposisi	SOP Pengumpul-an Bahan
4.	Mengonsep laporan konsinyering dan menyerahkan kepada Kabid					Bahan Laporan	2 jam	Konsep Laporan, Disposisi	
5.	Memeriksa konsep laporan konsinyering. Jika setuju menyampaikan kepada Asdep. Jika tidak setuju menyerahkan kepada Kasubid untuk diperbaiki.	Ya	Tidak			Konsep Laporan	1 jam	Draft Laporan, Disposisi	
6.	Memeriksa draft laporan konsinyering. Jika setuju menandatangani dan menyerahkan kepada Kabid. Jika tidak setuju mengembalikan kepada Kabid untuk diperbaiki.			Tidak	Ya	Draft Laporan	1 jam	Laporan, Disposisi	
7.	Menyerahkan laporan konsinyering kepada Kasubdit untuk didokumentasikan.					Laporan	10 menit	Disposisi	
8.	Menyerahkan laporan konsinyering kepada Analis untuk didokumentasikan.					Laporan	10 menit	Disposisi	
9.	Mendokumentasikan Laporan Konsinyering.					Laporan	15 menit	Laporan, Bukti Dokumentasi	

Gambar 0.1. Format Standar Operasional Prosedur (SOP)
Sumber: Kementerian PAN & RB, 2012

Based on this format, it is known that the SOP contains several parts, namely the description of activities, the implementation of the activity, and the standard quality (*input* and *output* and duration of the implementation of the activity). This format is in the form of *a flowchart* that outlines every activity carried out in the maintenance and maintenance work of concrete bridges in a sequence of standardized procedures. The activity description section contains the steps or procedures of each activity carried out in the Work Breakdown Structure level 5. The implementation section contains the perpetrators who are responsible for each description of the activities carried out. The standard quality section consists of *inputs*, *outputs*, and implementation duration. Input is the data/document needed to carry out an activity description, output is the result obtained after carrying out an activity description, and the duration of implementation is the time needed to complete an activity description, starting from the preparation of *input* to the *completion of output*.

Findings Research Quetions 1

As a first step, it should be emphasized that this research is specifically focused on the maintenance and maintenance aspects of concrete bridges, which includes both the elements of the lower and upper structures and their complementary buildings. The development of the Quality Management System (SMM) in this study is compiled based on ten main activities of concrete bridge maintenance and maintenance which refer to the Work Breakdown Structure (WBS) level 5.

The SMM document developed refers to the provisions of the Regulation of the Minister of Public Works No. 04/PRT/M/2009 and produces six main components of SMM for concrete bridge maintenance and maintenance work. These components consist of quality policies, quality targets, standard operating procedures (SOPs), work instructions, quality records or proof of work implementation, and quality manuals.

Furthermore, the SMM documents that have been compiled are validated through questionnaire methods and interviews with experts who have competence in the field of infrastructure quality control and construction. All SMM documents developed in this study are presented in full in the appendix.

The SMM document prepared aims to be a systematic and comprehensive quality manual, by containing a detailed description related to the six components of SMM in the implementation of concrete bridge maintenance and maintenance. A brief explanation of each component of SMM within the scope of this research will be presented in the following sections:

Based on the results of the validation carried out, all experts expressed agreement on the six main components in the Quality Management System (SMM) which refer to the Regulation of the Minister of Public Works No. 04/PRT/M/2009. The six components include quality policies, quality targets, Standard Operating Procedures (SOP), work instructions, quality records or proof of work, and quality manuals. Furthermore, each of these components is formulated through an archive analysis approach, so that four quality policies and four quality targets that are relevant for the maintenance and maintenance of concrete bridges are obtained.

Before compiling SOPs and work instructions, expert validation of the Work Breakdown Structure (WBS) standard is required, especially at the process and activity stages at level 5. This validation process results in ten concrete bridge maintenance and maintenance activities, namely: inventory checks, routine checks, detail checks, special checks, routine maintenance, periodic maintenance, damage repairs, element replacements, element modifications, and element additions. These ten activities are the basis for the preparation of SOPs, especially in the description of business processes or activity flows. The business process is then further detailed into ten work instructions that are systematically compiled so that they can be understood and implemented properly by all parties involved. To ensure the implementation of work instructions according to procedures, ten checklists and quality recording documents were also prepared that were tailored to each activity. This checklist and quality record serves as a control tool and proof that the implementation of the Quality Management System has been implemented in accordance with the set standards.

Findings and Discussion of Research Quetions 2 and 3

In this study, nine types of tests were carried out to analyze the relationship between variable X and variable Y. The first test was a data adequacy test, which aims to ensure that the number of respondents involved in the study is adequate.

The results of the analysis showed that the number of respondents as many as 45 people was sufficient to represent the population and support the validity of the research results. The second test is the homogeneity test, which groups respondents based on four categories, namely company, job title, work experience, and education level.

The results of this test show that there is no significant difference in the understanding or perception of respondents based on the category of Company and education. However, it was found that there was a significant difference in perception in respondents based on position categories.

The third test is the validity test, which aims to measure the extent to which a research instrument is able to measure what should be measured. The results of this test state that all variables, both variable X and variable Y, are declared valid and suitable for use in the study. The fourth test is the reliability test. Based on the results of this test, the research instrument in the form of a questionnaire was declared reliable, which means that the questionnaire has a high level of consistency and is reliable in measuring the variables studied.

The findings in this study were obtained through a series of processes that began with archival analysis and literature studies, which were then confirmed through validation by experts. Concrete bridge maintenance and maintenance activities are formulated based on applicable regulations, namely the Jasa Marga Guidelines No. 159/KPTS/2022 which regulates the handling and classification of types of damage to concrete bridges. Meanwhile, the process of developing Information System modeling on concrete bridges refers to previous research conducted by Yiye Xu and Yelda Turkan (2019), which is the foundation in the formulation of the BIM development stages. The processes and activities that have been compiled from these various sources are then validated by experts, and from the results of the validation three main groups of processes are obtained as follows: Actual data collection for SI development on concrete bridges. Compilation of a database of common types of damage to concrete bridges. Development of a database related to methods of handling damage to concrete bridges.

Through the expert validation process of the first and second problem formulations followed by testing on the third problem formulation, it is understood that the integration between the Quality Management System (SMM) and the Information System (SI) can be implemented by integrating the value of the bridge condition into the visual model of the information system. This condition is displayed through coloring of bridge elements that represent the level of damage, and is equipped with additional parameters in the form of data from previous inspections.

The integration of SMM with SI is supported by the development of a website-based information system that serves as the main platform for loading data, where bridge visualizations are also displayed in the system. This website is designed to host entire databases related to the maintenance and maintenance of concrete bridges that cannot be accommodated directly in the visualization software used.

The types of databases managed in the information system include: Data on the type of damage that occurs on concrete bridges, Recommendations for handling the identified damages, Supporting documents related to the implementation of the Quality Management System. The form includes a checklist and quality record that allows inspection officers to fill in and record maintenance and maintenance activities in accordance with procedures in SOPs and work instructions, as well as input data in real-time through this web-based system. The usability test of the information system is carried out using the System Usability Scale (SUS) method. Based on the results of the experts' assessment, the website obtained an average score of 65.83, which shows that the information system has been well developed and acceptable to users. However, the results also indicate that some minor improvements or developments are still needed for the system to function more optimally.

CONCLUSION

Based on the results of the study, it was found that the Quality Management System (SMM) in concrete bridge maintenance and maintenance work consists of six main components: quality policy, quality manual, quality targets, quality procedures, work instructions, and quality recording. These components are integrated with each other to ensure that the execution of the work runs according to standards. The performance indicators used to evaluate the success of maintenance include aspects of structural and traffic safety, durability, general conditions, availability levels, and the level of importance of the bridge. This research also details four quality policies and four quality goals that are the basis of the activity. Work activities are divided into three main stages, including inspection, maintenance, and maintenance, which are carried out through ten Standard Operating Procedures (SOPs). To support consistent implementation, work instructions, checklists, and quality recording documents that are valid and verified are also prepared. The quality manual developed has proven to be relevant and able to integrate all system components thoroughly.

In addition, the development of a website-based information system is a strategic step in facilitating the implementation of SMM and providing a database on the types and methods of handling bridge damage. The website received a score of 69.3 from the System Usability Scale (SUS) evaluation, indicating a good level of usability, although it still requires minor adjustments to be more optimal. The results of the study show that the integration between SMM and information systems has a positive impact on improving maintenance performance, with the contribution of information systems being more significant than the implementation of SMM alone. The relationship model developed also shows a significant influence between the implementation of SMM and the improvement of maintenance performance, especially on the indicator of bridge importance, with a contribution value of 59.9%. This shows that the combination of SMM and information technology is an effective approach in creating more quality and sustainable bridge management.

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