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# A COMPARISON OF METHODOLOGIES TO ASSESS BRIDGE CONDITION

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**ABSTRACT**

*Challenges such as corrosion and other deterioration phenomena can affect performance and disrupt bridge functionality. To address this need, a bridge management system is required to ensure optimal actions and strategies. Previous studies related to several condition assessment methods have been widely used, an in-depth review will be discussed in this paper. A comparison will be made to see the advantages and disadvantages. Three methods are reviewed and examined, the data used to determine the final condition is the result of visual inspection. BMS Indonesia uses a hierarchical system that still causes bias in its assessment. BHI uses condition state in its application, while BCR uses condition rating to determine the final value. BCR and BHI have advantages in assigning element importance weights, while BMS is good at considering each element's damage. Element importance weights are good to use in determining bridge condition values because they prioritize damage to crucial elements in the calculation. However, damage that occurs to supporting elements also needs to be considered because it can cause more serious damage if not treated further..*

**ABSTRAK**

Tantangan seperti korosi dan fenomena kerusakan lainnya dapat mempengaruhi kinerja dan mengganggu fungsionalitas jembatan. Untuk mengatasi kebutuhan ini, diperlukan sistem manajemen jembatan untuk memastikan tindakan dan strategi yang optimal. Penelitian sebelumnya terkait beberapa metode penilaian kondisi telah banyak digunakan, tinjauan mendalam akan dibahas dalam makalah ini. Perbandingan akan dilakukan untuk melihat kelebihan dan kekurangannya. Tiga metode ditinjau dan diperiksa, data yang digunakan untuk menentukan kondisi akhir adalah hasil inspeksi visual. BMS Indonesia menggunakan sistem hirarkis yang masih menimbulkan bias dalam penilaiannya. BHI menggunakan status kondisi dalam penerapannya, sedangkan BCR menggunakan rating kondisi untuk menentukan nilai akhir. BCR dan BHI memiliki kelebihan dalam menetapkan bobot kepentingan elemen, sedangkan BMS baik dalam mempertimbangkan kerusakan setiap elemen. Bobot kepentingan elemen baik digunakan dalam menentukan nilai kondisi jembatan karena memprioritaskan kerusakan pada elemen krusial dalam perhitungan. Namun, kerusakan yang terjadi pada elemen pendukung juga perlu dipertimbangkan karena dapat menyebabkan kerusakan yang lebih serius jika tidak ditangani lebih lanjut..

## INTRODUCTION

Nowadays, infrastructure development continues to grow in order to improve connectivity and support regional economic growth. Bridges are one of the infrastructure elements that play an important role in maintaining the connectivity and sustainability of the transport system (Chassiakos et al., 2005). Given the important role of bridges, evaluating the condition value is crucial to ensure that the infrastructure can function optimally, safely, and efficiently. So, in order to maintain its functionality, maintenance efforts such as routine inspections need to be carried out (Wahyudhi et al., 2018). Increased traffic volumes as well as overloading from vehicles can cause many bridges to fail early on. To overcome this, bridges must be managed properly, thus requiring systematic implementation and proper procedures. Therefore, a bridge management system is needed to ensure optimal actions and strategies.

In Indonesia, the bridge management system is known as the Bridge Management System (BMS) (now the 2022 Bridge Inspection Guidelines) and has been implemented since 1993. In its application, this system still needs to be improved (Puspitasari et al., 2022), this is because the assessment carried out hierarchically causes bias in the final results so that there is similarity in bridge assessment and allows less accurate results (Nugroho, 2017; Vaza, 2016; Wahyudhi et al., 2018). In contrast to the Indonesian BMS, one method for assessing bridge conditions is the Bridge Health Index (BHI). This method plans a bridge monitoring programme by calculating the residual value of a bridge determined by the condition ratio of its elements, taking into account failure costs, repair costs, or predetermined weights (Inkoom et al., 2017; Jiang & Rens, 2010b; Sobanjo & Thompson, 2016; Wakchaure & Jha, 2012).

In addition, another method that can also be used is the Bridge Condition Rating (BCR). The bridge assessment is carried out by considering the weight of the bridge elements that have been determined based on the importance of the elements (Harywijaya et al., 2020; NYSDOT, 1997). This paper aims to assess the efficiency of applying the three methods in identifying and evaluating bridge conditions, then will compare to see if there are significant differences in assessment methods and have an influence on bridge handling decision-making. The assessment results can be used as suggestions and considerations for making the right decisions for bridge owners.

## RESEARCH METHODS

This paper uses a perspective approach or literature method. The preparation of this paper was carried out through a literature review method consisting of four stages of study. The initial stage includes topic selection, followed by searching for relevant articles, analysing and synthesising the literature, and collecting data from the literature to be compiled into a paper.

### 1. Bridge Management System (BMS)

In Indonesia, the management system is known as the Bridge Management System (BMS) (now Bridge Inspection Guidelines 2022) and has been implemented since 1993. The assessment is carried out through a detailed inspection, which aims to evaluate the overall condition of the bridge based on the condition of the components and elements according to their damage value. The assessment is based on a hierarchical system of elements, from the lowest element (Level 5) to the highest element (Level 1). In an effort to simplify the assessment procedure, only elements that have damage are recorded and will be assessed based on the values of Structure (S), Damage (R), Quantity (K), Function (F), and Effect (P), where these values will relate to questions related to bridge damage and a value of 1 or 0 is given to the element according to each existing damage as in Table 1 (Direktorat Jenderal Bina Marga, 2022).

After checking the condition value of elements at Level 5, Level 4, and Level 3, condition assessments are then carried out for elements at higher levels in the hierarchy to obtain the condition value (NK) of the bridge. Contrary to the Level 5 - 3 assessment, at Level 2 and 1, the examination of the condition value of the bridge elements only takes into account the structural elements in accordance with the classification of elements listed in Guideline 2022. This is related to the allocation of bridge rehabilitation and replacement funds, which are mostly intended for bridge structural elements (Irawan et al., 2023). The final scores of the overall bridge assessment can be seen in Table 2 (Direktorat Jenderal Bina Marga, 2022).

**Table 1 Criteria for Determining Bridge Condition Score**

| Assessment System | Element Criteria | | Value |
|---|---|---|---|
| Structure (S) | The structural condition of an element | Harmful | 1 |
| | | Harmless | 0 |
| Damage (R) | The extent of the damage level of an element | Severe | 1 |
| | | Not Severe | 0 |
| Quantity (K) | The rate of development of an element's damage volume | More than 30% for structural elements and 50% for non-structural element | 1 |
| | | Less than the above value | 0 |
| Function (F) | | Functioning elements | 1 |

| | | | |
|---|---|---|---|
| | Whether the element is still working or not | Not functioning | 0 |
| Impact (P) | Whether damage to an element has a serious effect on other elements | Affects other elements | 1 |
| | | Not Affect other elements | 0 |
| Condition Value (NK) | S + R + K + F + P | | |

**Table 2 Description of Condition Values**

| NK | Bridge Condition | Handling Suggestions |
|---|---|---|
| 0 | Bridge in good condition | Routine Maintenance |
| 1 | The bridge is in a lightly damaged condition, where the damage can be repaired through routine maintenance, and has no impact on the safety or function of the bridge | |
| 2 | The bridge is in a moderately damaged condition, where the damage requires monitoring or maintenance in the future | Periodic Maintenance |
| 3 | The bridge is in a state of serious disrepair, where the disrepair requires attention as the damage is likely to become serious within 12 months | Rehabilitation and/or retrofitting |
| 4 | The bridge is in critical condition, where serious damage requires immediate attention | Retrofitting or replacement |
| 5 | The bridge is in a collapsed condition, where the bridge is collapsed and not functioning. | Replacement |

## 2. Bridge Health Index (BHI)

Bridge Health Index was first implemented on bridges in California (Shepard & Johnson, 2001), and later adopted by AASHTOWARETM and BrM (formerly Pontis) (Chase et al., 2016). This method uses element condition ratios to obtain bridge condition marks, which are described by numerical values of 0-100 as confidence from element inspection data. This method covers all condition states by assigning weights to each element based on replacement cost, failure cost, or other appropriate weights (Sobanjo & Thompson, 2016). The Health Index (HI) can be calculated using the Equation 1 – 4 (Shepard & Johnson, 2001).

$$\mathrm{HI} = \frac{\sum \mathrm{CEV}}{\sum \mathrm{TEV}} \times 100 \quad (1)$$

$$\mathrm{TEV} = \mathrm{TEQ} \times \mathrm{FC} \quad (2)$$

$$\mathrm{CEV} = \sum(\mathrm{QCS} \times \mathrm{WFi}) \times \mathrm{FC} \quad (3)$$

WF = [1 – (Condition State # - 1)(1/State Cpunt – 1)] (4) where QCS is the quantity in the condition state, WF is the weighting factor, FC is the element failure cost, TEV is the total element value, TEQ is the total element quantity, and CEV is the current element value. The cost used can be either repair cost or element failure cost.

In determining the conditon value of the bridge, further studies related to equations 1-4 were conducted by Jiang and Rens (Jiang, 2012; Jiang & Rens, 2010a). It was found that the health index does not accurately represent the value of the bridge due to the relatively small value, the sensitivity of the health index variation to the element is still lacking, and it is still subjective because it uses the cost data of a city which is often inaccurate. Therefore, improvements were made on the premise that element weighting theory should emphasize the impact of element damage on bridge health and function (Jiang & Rens, 2010b). Three modifications were made, including the removal of element costs from the formula, the introduction of non-linear index coefficients, and the adjustment of weights. To present the rationale, a description of the conditions using the Health Index zones shown in Table 3. Equations 5-7 provide the method for calculating the Health Index.

$$H_e = \frac{\sum k_s^n q_s}{\sum q_s} \times 100\% \tag{5}$$

$$we_e^{aj} = w_e \times AF_e \tag{6}$$

$$BHI = \frac{\sum H_e we_e^{aj}}{\sum we_e^{aj}} \times 100 \tag{7}$$

where $q_s$ is the element quantity, $k_s^n$ is the coefficient on the condition state, $we^{aj}$ is the element weight coefficient, $AF_e$ is the element adjustment factor determined by Figure 1.

**Table 3 Bridge Healt Index Description**

| BHI | Description Condition |
|---|---|
| 85 – 100 | Excellent-No noticeable defects, some aging or wear visible |
| 70 – 84 | Very good-Only minor deterioration or defects evident |
| 55 – 69 | Good-Some deterioration or defects evident, function not impaired |
| 40 – 54 | Fair – Moderate deterioration, function not seriously impaired |
| 25 – 39 | Poor-Serious deterioration in at least some portion of structure, function seriously impaired |
| 10 – 24 | Very poor-Extensive deterioration, barely functional |
| 0 – 9 | Failed-General failure of major component no longer functional |

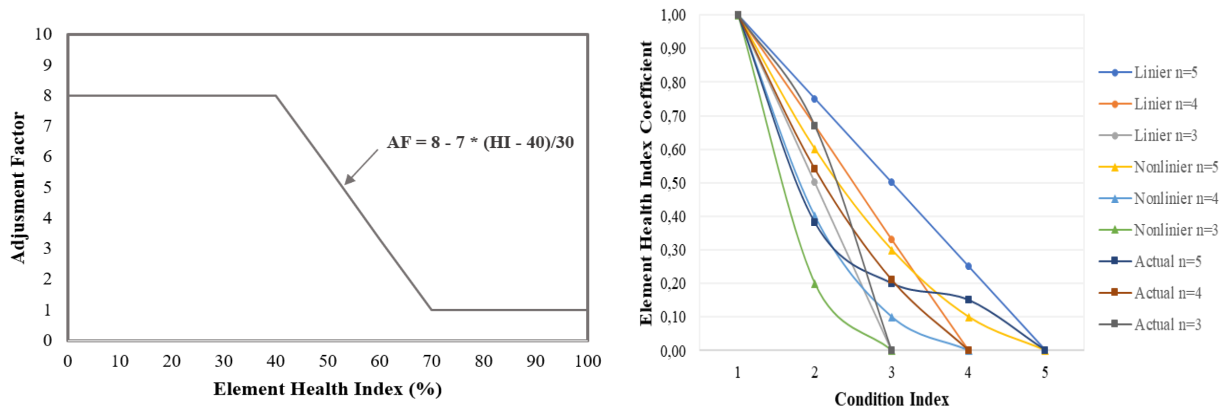


**Figure 1 Adjustment Factor ((Greimann et al., 1991)(a) Comparison of linear, nonlinear and actual Health Index coefficients (Jiang, 2012) (b)**

To evaluate the impact of each element on the overall bridge construction, weighted coefficients based on Jiang's study were used (Jiang & Rens, 2010b). The adjustment factor is used to amplify the impact of elements in poor condition on the BHI value. (Inkoom et al., 2017), conducted an assessment with and without the use of adjustment factors, it was found that the use of adjustment factors more objectively describes the effect of elements on the bridge as a whole. Determination of the coefficient on the condition state using Equation 8. The HI coefficient is a multiplier to determine the health index value of an element against the corresponding quantity.

$$k_s = \frac{n-s}{n-1} \quad (8)$$

where $k_s$ is the health index coefficient of the condition state, $n$ is the number of condition state usage (n = 3, 4, and 5), and $s$ is the condition state index (s = 1, 2, ..., n).

In Jiang and Rens' study (Jiang & Rens, 2010b), linear coefficients were used, and irrational results were obtained, so to make HI more conservative, the use of non-linear coefficients was introduced, as shown in Table 4. For the determination of HI coefficients, this study uses three approaches, including linear, nonlinear, and actual coefficients presented in Figure 1b.

**Table 4 Health Index Non-Linear Coefficient**

| Number of Condition States | CS 1 | CS 2 | CS 3 | CS 4 | CS 5 |
|---|---|---|---|---|---|
| **5** | 1.00 | 0.35 | 0.20 | 0.15 | 0.00 |
| **4** | 1.00 | 0.54 | 0.21 | 0.00 | |
| **3** | 1.00 | 0.67 | 0.00 | | |

In this method, to determine the value of the bridge, a visual assessment is required based on the condition state. Assessment guidelines can be found in the

AASHTO Manual for Bridge Element Inspection (AASHTO, 2019). Element reviews can include a review of field inspection records and photographs. In general, the scale in condition states is Goods (CS 1, no deterioration to minor deterioration), Fair (CS 2, minor to moderate deterioration), Poor (CS 3, moderate to severe deterioration), and Severe (CS 4, more severe deterioration than CS 3).

Condition Index (CI) is a numerical measure that represents the condition of a bridge structure, with a value of 0% indicating the lowest condition and 100% indicating the highest condition. This index systematically evaluates and ranks the structure and its constituent elements. The Health Index is intended to focus management on structures that are most likely to require repair and further evaluation. For this reason, the health index zones that have been used by the U.S. Army Corps of Engineers (USACE) as in Table 5 are adapted to provide action suggestions based on the resulting health index.

**Table 5 Condition Index Handling Recommendation**

| Zone | CI (%) | Handling Recommendations |
|---|---|---|
| 1 | 70 – 100 | Immediate action is not required |
| 2 | 40 – 69 | Economic analysis of repair alternatives is recommended to determine appropriate action |
| 3 | 0 – 39 | Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended |

### 3. Bridge Condition Rating (BCR)

BCR is a bridge condition index used in the Bridge Management and Inventory Manual method by the New York State Department of Transportation (NYSDOT). In calculating the bridge condition value, this method uses the predetermined element component weights, which are then substituted into Equation 9 (Subagio et al., 2008).

$$BCR = \frac{\sum(Component\ rating\ x\ weight)}{\sum Weightings} \quad (8)$$

where BCR is the value of the bridge condition, component rating is the value that describes the condition of the element, weight is the weight of the element component, and weightings are the total weight of the element component. The element component weights used can be seen in Table 6 (NYSDOT, 2004).

Component rating is obtained from the existing condition of the bridge, which is done by giving condition values from 1-9. However, a value of 8 is given for conditions where the bridge has no components under review, while a value of 9 is given when the condition of the component is unknown because it is not visible (only for footings and piles), so the component rating assessment only uses values 1-7.

**Table 6 Weighting of Bridge Components**

| No | Component | Weight |
|---|---|---|
| 1 | Primary Members | 10 |
| 2 | Abutment | 8 |
| 3 | Piers | 8 |
| 4 | Structural Deck | 8 |
| 5 | Bridge Seats | 6 |
| 6 | Bearings | 6 |
| 7 | Wingwalls | 5 |
| 8 | Backwalls | 5 |
| 9 | Secondary Members | 5 |
| 10 | Joints | 4 |
| 11 | Wearing Surface | 4 |
| 12 | Sidewalks | 2 |
| 13 | Curbs | 1 |

Systematically, the rating scale is 7-indicating new condition, 5-minor deterioration but can function as originally designed, 3-serious deterioration or cannot function as originally designed, 1-overall deterioration (failed condition). Values 2,4,6 are intermediate conditions. Then for the proposed handling based on the condition value can be seen in Table 7 (NYSDOT, 2003).

**Table 7 Suggested Handling**

| BCR | Condition | Suggested Handling |
|---|---|---|
| 1,000 – 3,000 | Poor | Replacement |
| 3,001 – 4,999 | Fair | Rehabilitation |
| 5,000 – 6,000 | Good | Routine and periodic maintenance |
| 6,000 – 7,000 | Very Good | |

## RESULTS AND DISCUSSION

The three methods have different rating systems. BMS Indonesia uses a hierarchical element system, BHI uses a condition state, and BCR uses a component rating. The differences between the three methods are summarised in Table 8.

**Table 8 Comparison of Bridge Assessment Methods**

| Item | BMS Indonesia | BHI | BCR |
|---|---|---|---|
| **Assessment Aspects** | There are five aspects of assessment, Structure (S), Damage (R), Function (F), Quantity (K) and Impact (P) | Assessment based on bridge element condition ratio | Assessment based on condition rating of 13 component elements |

| | | | |
|---|---|---|---|
| **Element** | Bridge elements that have been adapted to common bridge types in Indonesia | The main elements (cores) that are considered crucial for the bridge from some common bridge types | Consists of 13 main element components |
| **Element Importance Weight** | None | Uses weights that can be assigned based on the replacement cost, repair cost, and importance of the element. Weights are determined depending on the policies of the country of use | Using predetermined weights |
| **Assessment Procedure** | Based on the hierarchical assessment of the damaged elements from level 5 to level 1 | Based on the assessment of bridge elements that are damaged and then grouped based on Condition State | Based on the assessment of bridge elements that are damaged |
| **Range Value** | 0 - 5 | 0 – 100% | 1 - 7 |
| **Bridge Handling Priority** | Through technical screening and economic evaluation | Can be organized based on inspection bridge condition | |
| **Handling Recommendations** | There are recommended forms of treatment that can be done | No specific recommendations, just a general description | |
| **Difficulty of Use** | There are many aspects and elements of the bridge that need to be assessed and analysed in the process of determining the condition value | There are difficulties when measuring damage quantity and total elements | Has limitations on the assessment of invisible elements |

The ranking system used by BMS still relies on a hierarchical system of elements, this results in the final value obtained not being able to describe the overall condition of the bridge because it is only based on dominant damage. This is in line with the opinion of (Vaza et al., 2017), which explains that based on its application, BMS is difficult to define bridge assessments when evaluating its condition, the results obtained do not always represent the actual conditions in the field and the importance of bridge elements to the overall bridge condition is not clear.

The BHI uses element importance weights in its ranking system, so that condition assessment is carried out based on the level of element importance. However, in describing the value of bridge conditions, other aspects such as structural capacity, traffic, etc., are not taken into account. In addition, the handling that corresponds to the overall bridge condition value is not known with certainty because it is only a description of the condition. Similarly, with the BCR method, the assessment is carried out based on 13 main components. Supporting elements such as drainage and backrest are not calculated (Harywijaya et al., 2020). It is important to consider damage that occurs to nonstructural elements, as it can cause damage to structural element failure if not addressed early.

The three methods have the same goal of describing the condition of the bridge based on visual inspection, but in identifying the existing conditions, these methods have different ways. In its application, different from BHI and BCR, BMS Indonesia has an advantage in the assessment of its elements. BMS takes into account every component of structural and nonstructural elements. However, the hierarchical process makes the final value of BMS biased. BHI and BCR have advantages in the weighting of core elements. BCR has limitations in that the assessment is only focused on 13 component elements. BHI can be more flexible in its use.

## CONCLUSION

The need for efficient and systematic bridge management has become very important in recent years. Bridge management systems have become important in its management. This paper provides a comparison and overview of three bridge management systems that can be applied in decision-making. In its application, the BHI and BCR methods are superior in terms of weighting the importance of elements. With the weighting of the importance of elements, bridges that have damage to crucial elements will be prioritised. On the other hand, although BMS does not have element importance weights, this method considers each element's damage in its assessment. The BHI method can be more flexible in its use because the element weights and components can be adjusted to the policies of the user area. In terms of bridge inspection, condition assessment based on data collected through visual inspection is the main tool in assessing structural conditions. Further studies on the application of this method in case studies are needed.

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