E-ISSN: 2528-388X
P-ISSN: 0213-762X

INERSIA
Vol. 20, No. 01, May 2024

Bridge Assessment Analysis using Sufficiency Rating Method (Case Study of The Mungkung Overpass)

Debora Lau, Akhmad Aminullah*, Andreas Triwiyono

Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

Keywords:
Bridge Assessment
Mungkung Overpass
Sufficiency Rating

ABSTRACT

Bridges play a crucial role in connecting various routes and water bodies, necessitating regular monitoring to prevent potential hazards and losses due to deterioration. In Indonesia employs the Bridge Management System (BMS) for decision-making regarding maintenance, repair, and replacement activities, its reliance on a limited set of criteria may lead to uncertainties in bridge condition assessmsents. This study explores the Sufficiency Rating (SR) method as an alternative for assessing bridge feasibility. By considering multiple factors, including structural adequacy, serviceability, functionality, and public interest, the SR method offers a comprehensive approach to bridge evaluation. An analysis of the Mungkung Overpass on the Ngawi Kertasono toll road was conducted to evaluate the effectiveness of the SR method. The findings classified the bridge as excellent, indicating no immediate need for treatment. However, the SR method has limitations, particularly in visually assessing damage to superstructure and substructure elements, which may introduce subjectivity. Overall, this research contributes to the ongoing development of bridge assessment methodologies in Indonesia, aiming to enhance decision-making processes and ensure the safety and longevity of bridge infrastructure. After analyzing the data obtained through the implementation of the SR method, it was revealed that S1 achieved a value of 45%, S2 achieved 23%, S3 achieved 12.7%, and S4 achieved 6%. The total actual value of the four parameters calculated based on the SR method was 74.7%, with a difference of 25.3% from the maximum value. These findings clearly illustrated that the bridge satisfied the criteria for deficiency, thereby necessitating comprehensive rehabilitation measures to be undertaken.

This is an open access article under the CC–BY license.

1. Introduction

A bridge is a structure that connects interrupted routes or crossings such as rivers, lakes, straits, channels, roads, and the like. Over time, the life of the bridge will naturally decrease. Therefore, it is important to regularly monitor the condition of the bridge to prevent sudden collapse that can cause both material and non-material losses. Bridge collapse can disrupt various socio-economic sectors such as education, trade, and health in society [1].

In Indonesia, the BMS (Bridge Management System) has been implemented for bridge condition assessment, which considers 5 aspects of the criteria set by the Ministry of Public Works and Public Housing. Damage assessment criteria are based on the value of Structure (S), Damage (R), Quantity (K), Function (F), and Effect (P). From these criteria, a condition value will be obtained with a range of 0 (Good) to 5 (Collapse). Then, the condition value identifies the type and level of repair needs, decision-making related to priorities, preparation of maintenance plans, and bridge rehabilitation. Because the BMS method only considers damage parameters in decision-making, it can cause uncertainty or inaccuracy in the assessment of bridge condition values [2]. In contrast to the condition assessment by the Federal Highway Administration (FHWA) which not only considers damage parameters, but also pays attention to other

*Corresponding author.
E-mail: akhmadaminullah@ugm.ac.id

http://dx.doi.org/10.21831/inersia.v19i1.71384
Received February 12st 2024; Revised April 18th 2024; Accepted May 17th 2024
Available online May 31th 2024

aspects such as Average Daily Traffic, Detour Length, Traffic Lanes, Structure Type, Structural Evaluation, and Inventory Rating [3]. The many parameters make the SR method more accurate in terms of decision-making. The analysis results provide the status of the bridge and handling recommendations.

The bridge structure will deteriorate with the age of the bridge so it must be maintained and rehabilitated so that it can continue to function. Therefore, it is necessary to prioritize bridge preservation [4]. In this study, the NBI historical significance SR was utilized in a selection matrix design. Bridge inventory is first sorted using this matrix as a tool. According to the bridge prioritization results, SR and NBI historical relevance are insufficient criteria for correctly prioritizing bridges. To ensure more accurate results in this study, it is advised to adopt a more focused methodology for bridge prioritizing, such as qualitative methodologies.

Method for assessing bridge resilience based on various factors such as replacement cost, consequences of events, user cost, foundation type, support type, overload, strength reduction factor, and protection from erosion. The method includes a quantitative approach by incorporating weighting factors to calculate the bridge resilience assessment, as well as tables and equations to calculate the resilience assessment. The research also shows that sufficiency assessment alone does not fully reflect bridge resilience, and that the two quantities together provide a more complete assessment of a bridge's condition. In addition, this research also provides an overview of the resilience assessment for four case study bridges in Arizona, with a detailed discussion of the resilience assessment for each bridge [5].

New process for the evaluation of the condition of concrete, steel, masonry, and timber bridges through visual inspection which is shown for general maintenance planning within the framework of the BMS. This study aims to plan maintenance interventions, forecast future structural conditions, and assess the bridge's state by visual examination. As a result, combining the Total Sufficiency Rating (TSR), Element Sufficiency Rating (ESR), and Condition Value (CV) approaches for the evaluation of the current condition through visual inspections. The findings demonstrate that multiple bridge maintenance may be prioritized based on the level of damage to a single component and that a bridge maintenance plan can be created by taking the overall efficiency into consideration through TSR [6].

The construction and verification of Markov systems for forecasting the deterioration of bridge and culvert conditions in Texas based on a period data. The models were developed using Markov methodology and classified into groups depending on criteria including age, material type, and traffic. The models provide probabilities of condition ratings decreasing over a 2-year inspection cycle and were validated and implemented for forecasting the eventual state of the bridge and drainage connection. The research aims to fulfill a Federal Highway Administration requirement for forecasting the deterioration of bridge and pavement assets. The study emphasizes the importance of accurate deterioration forecasts for bridge management and acknowledges the support of the National Bridge Inventory Federal Highway Administration (NBI FHWA) for the research [7].

Prioritizing maintenance of bridges should be conducted by condition and effect on the transportation system, given the limited resources available for this purpose. According to the Federal Highway Administration's inquiry, the majority of US transportation authorities continue to heavily depend on SR as a qualitative measure of bridge functionality and safety when allocating funding to less suitable bridges. The purpose of this research is to offer a methodical, quantitative risk-based approach to bridge grading. To more precisely assess the likelihood and effects of bridge failure, the suggested method combines traffic network analysis, public datasets, and structural reliability analysis. Thus, the SR-Based Bridge Ranking and Risk-Informed Bridge Ranking methods are used [8].

Bridge condition ratings have been produced using a variety of methods. Consideration of methods using the BCR (Bridge Condition Rating) [9] [10], BHI (Bridge Health Index) [11][12], and BCI (Bridge Condition Index) [13][14][15][16] techniques as condition ratings. Based on some of the previous research, several previous studies have indicated that the SR method could be considered as an alternative for the development of existing methods used in assessing bridge feasibility. In existing assessments conducted using the BCR, BHI, and BCI methods, the weight of the elements was considered one of the parameters for determining the bridge's condition. In contrast, assessments employing the SR method were more detailed, considering numerous parameters such as ADT, lane on structure, under clearance, structural evaluation, deck geometry, physical condition of elements, approach roadway alignment and width, and inventory rating. The inventory rating parameter provided more objective results as it factored in the rating factor to determine the bridge capacity. The SR method can be an alternative in developing existing methods for assessing the feasibility of bridges. In addition, The SR method has never been applied to determine the feasibility of bridges in Indonesia, therefore the SR method is a new research on bridges in Indonesia.

2. Methods

2.1 Research Methodology

The step of this research can be seen in Figure 1. The first step involved conducting a literature study aimed at developing theoretical and practical aspects to identify problems from research journals and books. Information about the problems, methods, and topics to be developed was provided by the literature study. The Condition Value was developed using the SR FHWA method [17]. This research was conducted at Ngawi Kertasono Toll Road with a case study conducted at Mungkung Overpass KM 643+300 can be seen in Figure 2.

In the next step, applicable standards and theories in the selected method were collected and understood to continue the research. Secondary data collection took the form of inventory data (name, location, structure type, length, width, height, construction year, condition, maintenance history, and bridge photos), documentation of element damage, as-built drawings, detailed inspection data, LHR data, and primary data through visual inspection of the overpass, which was the object of research. The results of the visual inspection were followed by the use of the FHWA SR method for the bridge condition assessment system [17].

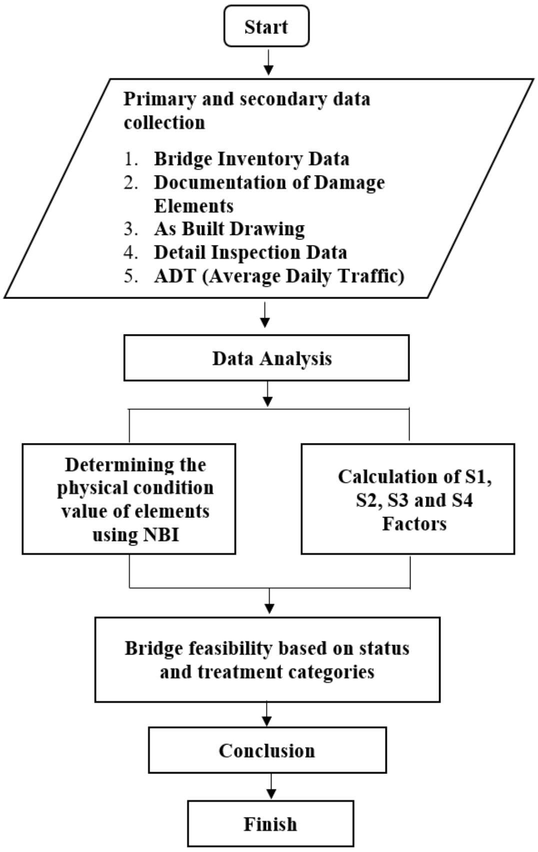

Figure 1. SR FHWA calculation flow chart

Figure 2. Research Location Mungkung Overpass, Ngawi Kertosono Toll Road KM 643+300

2.2 National Bridge Inventory (NBI)

Bridge condition assessments using NBI were generally carried out on a scale of 0 to 9. The most typical assessment scores for operational bridges were between 4 and 7. To conduct a bridge assessment using the SR method, Table 1 was referred to for the NBI items that would be components in the SR calculation. For example, the applicable NBI codes and associated definitions for deck, superstructure, and substructure condition assessments were given to provide an overview of how condition assessments were performed using the NBI data. The NBI assessment could be seen in Table 2, but for assessments such as structural evaluation, inventory rating, Approach roadway width, deck geometry, and traffic safety features, the table in FHWA, 1995 was used. [17] [18].

Table 1. Condition rank NBI [18]

Code	Condition	Description
N	Not Applicable	Component does not exist.
9	Excellent	Isolated inherent defects.
8	Very good	Some inherent defects.
7	Good	Some minor defect.
6	Satisfactory	Widespread minor or isolated moderate defects.
5	Fair	Some moderate defects; strength and performance of the component are not affected.
4	Poor	Widespread moderate or isolated major defects; strength and/or performance of the component is affected.
3	Serious	Major defects; strength and/or performance of the component is seriously affected. Condition typically necessitates more frequent monitoring, load restrictions, and/or corrective actions.
2	Critical	Major defects; component is severely compromised. Condition typically necessitates frequent monitoring, significant load restrictions, and/or corrective actions in order to keep the bridge open.
1	Imminent Failure	Bridge is closed to traffic due to component condition. Repair or rehabilitation may return the bridge to service.
0	Failed	Bridge is closed due to component condition, and is beyond corrective action. Replacement is required to restore service.

2.3 Sufficiency Rating (SR)

Based on FHWA (1995) [17], bridge assessments to determine the value of bridge conditions were carried out by the National Bridge Inventory guidelines [18]. The viability of the bridge was assessed using the SR Method analysis for determining when it requires replacement or rehabilitation. The SR formula was a technique for assessing bridge data that involved multiplying and summing four different variables to produce a numerical value indicating the adequacy of the bridge to continue operating. A bridge with a rating of 100 was considered entirely adequate, whereas a bridge with a rating of 0 was considered fully inadequate or deficient. The factors used for the SR analysis were listed in Table 2.

It was necessary to obtain an index of numbers on every bridge, and weighting factors were applied to many bridge metrics and qualities in a complex formula used to calculate SR. The general formula, as expressed in Equation 1.

$$SR = S_1 + S_2 + S_3 - S_4 \quad (1)$$

Table 2. Value factor SR [17]

Factor	Maximum	Consideration
Structural adequacy and safety (S_1)	55%	Superstructure Substructure Inventory rating
Serviceability and functional obsolescence (S_2)	30%	Lanes on structure Average daily traffic Approach roadway width Structure type Bridge roadway width Vertical clearance over deck Deck condition Structural evaluation Deck geometry Under clearance Approach roadway alignment
Essentiality for public use (S_3)	15%	Detour length Average daily traffic
Special reductions (S_4)	13%	Detour length Traffic safety features Structure type

where S_1 represented structural adequacy and safety, S_2 represented serviceability and functional obsolescence, S_3 was essential for general use, and S_4 involved special reduction. To calculate the S_2 value, a Rating Reduction was required to assess the adequacy or condition of the bridge, with a maximum value of 13%. The Rating Reduction value was obtained from the deck condition, the structural evaluation, the deck geometry, the under clearance, the approach roadway alignment, and the traffic safety feature.

(a) Deck condition
Deck condition refers the state level for the entire deck. The concrete deck should be checked for cracking, flaking, spalling, softening, pitting, and partial or complete failure of thickness.

(b) Structural evaluation
The values of Average Daily Traffic (ADT) and Inventory Rating were compared using Table 3 to assess the structural evaluation.

(c) Deck geometry
In this section, the minimal vertical clearance over the bridge roadway was compared with functional categorization provided in Table 4.

(d) Under clearance
The minimum vertical under clearance was assessed by comparing it with the classification of under passing route using Table 5. If it was a river bridge, (N) was specified, indicating that extraction from this item was not continued.

Table 3. Relationship between ADT and IR [17]

Structural Evaluation Rating Code	Inventory Rating		
	Average Daily Traffic (ADT)		
	0-500	501-5000	>5000
9	>32.4	>32.4	>32.4
8	32.4	32.4	32.4
7	27.9	27.9	27.9
6	20.7	22.5	24.3
5	16.2	18.0	19.8
4	10.8	12.6	16.2
3	Inventory rating less than value in rating code of 4 and requiring corrective action.		
2	Inventory rating less than value in rating code of 4 and requiring replacement.		
1 and 0	Bridge closed due to structural condition.		

Table 4. Relationship between minimum vertical clearance over bridge roadway and functional classification [17]

Vertical Clearance Rating Code	Minimum Vertical Clearance		
	Functional Class		
	Interstate and Other Freeway	Other Principal and Minor Arterial	Major and Minor Collectors and Locals
9	>5.18	>5.02	>5.02
8	5.18	5.02	5.02
7	5.10	4.72	4.72
6	5.02	4.41	4.41
5	4.80	4.34	4.34
4	4.57	4.26	4.26
3	Vertical clearance less than value in rating code of 4 and requiring corrective action.		
2	Vertical clearance less than value in rating code of 4 and requiring replacement.		
1 and 0	Bridge closed.		

Table 5. Relationship between minimum vertical under clearance and functional classification of under passing route [17]

Under clearance Rating Code	Minimum Vertical Under clearance		
	Functional Class		
	Interstate and Other Freeway	Other Principal and Minor Arterial	Major and Minor Collectors and Locals
9	>5.18	>5.02	>5.02
8	5.18	5.02	5.02
7	5.10	4.72	4.72
6	5.02	4.41	4.41
5	4.80	4.34	4.34
4	4.57	4.26	4.26
3	Under clearance less than value in rating code of 4 and requiring corrective action.		
2	Under clearance less than value in rating code of 4 and requiring replacement.		
1 and 0	Bridge closed.		

(e) Approach roadway alignment
Approach Roadway Alignment detects bridges that fail to operate correctly or effectively as a result of issues with the positioning or adjustment of the approach roadways to the bridge. This may result in difficulties or limitations in the use or accessibility of the bridge (can be visually assessed) using Table 6.

Table 6. Rating approach roadway alignment [17]

Approach roadway alignment	Description
9	Superior to the current desired standard. (no intersections within 1 km of the bridge so no need for speed reduction).
8	In accordance with current desired criteria (there are no intersections within 1 km of the bridge so no need for speed reduction).
7	Better than current minimum criteria (no speed reduction).
6	Very small and almost imperceptible speed drop.
5	If the road can be driven safely and the posted speed is not lower than 20 km/h below the posted speed limit.
4	Steep gradients, sharp curves, speeds below the limit of more than 20 km/h, sharp curves with limited visibility.
3	Only if the horizontal or vertical curvature requires a significant reduction in vehicle speed from the speed on the highway section.
2	If the combined effect of horizontal and vertical alignment forms a dangerous situation (for example, a very steep hill combined with a sharp needle-like bend).
1 and 0	Bridge closed.

(f) Traffic Safety Feature
The traffic safety feature was defined as a bridge inspection during which information about traffic safety features had to be recorded in order to evaluate safety using Table 7.

Table 7. Traffic Safety feature value [17]

Code	Description
0	Checked features do not meet the as built drawing/design (safety features but none are provided.
1	Checked features meet the as built drawing/design.
N	Not applicable or no security features required.

After the SR analysis was conducted, handling recommendations based on the status of the bridge were displayed as shown in Table 8.

Table 8. SR status and treatment categories [19]

SR (%)	Classification	Treatment Category
<50	Deficient	Replacement
50-80	Deficient	Rehabilitation
>80	Excellent	None

3. Results

Sufficiency rating is obtained of structural adequacy and safety with a maximum value of 55%, serviceability and functional obsolescence with a maximum value of 30%, essentiality for public use with a maximum value of 15% maximum, and special reductions with a maximum value of 13%. Structural adequacy and safety consist of superstructure and substructure condition obtained from visual inspection with a rating value of 7 as seen in Table 1, resulting in an A value of 0%; Inventory Rating (IR) is generated from the calculation of the Rating Factor (RF), which represents the bridge's capacity to carry loads producing moment and shear values [20]. The IR value obtained is 107.3, resulting in a B value of 0%. Based on these two values, the S1 value is 55%. This value equals the maximum value, indicating that the Structural Adequacy and Safety conditions are categorized as good.

The serviceability and functional obsolescence assessment, it comprise several components: the deck condition value evaluated using Table 1; Structural Evaluation, by comparing ADT and IR values in Table 3; deck geometry, determined by comparing the minimum vertical clearance over the bridge roadway with the functional classification in Table 4; under clearance, by comparing the minimum vertical clearance over the bridge roadway with the functional classification; and Approach Roadway Alignment, assessed visually and rated according to Table 6. These parameters collectively resulted in an F value of 2%. The roadway width insufficiency assessment was calculating by comparing the bridge roadway width parameter with approach roadway width, resulting in a G value of 5%. Combining these parameters, the S2 value obtained was 23%.

Furthermore, the assessment of essentiality for public use is obtained by comparing ADT and Detour Length, resulting in an A value of 2.3%. Subsequently, from this value, S3 is obtained as 12.7%. Special Reduction is calculated if the sum of S1, S2, and S3 exceeds 50%. Therefore, to determine the value of S4, consideration must be given to detour length reduction, structure type, and traffic safety features obtained from Table 7.

Table 9. SR calculation

1. Structural Adequacy and Safety (55 maximum)	
a. Only the lowest rating code of item 59 and 60 applies	
Item 59 (Superstructure Condition)	= 7
Item 60 (Substructure Condition)	= 5
b. Reduction for Load Capacity	A = 10%
$B = (32.4 - IR)^{1.5} \times 0.3254$	
Item 66 (Inventory Rating)	= 86.7
	B = 0%
$S_1 = 55 - (A + B)$	$S_1 = 45\%$
2. Serviceability and Functional Obsolescence (30% maximum)	
a. Rating Reductions (13% maximum)	
Item 58 (Deck Condition) =	6
	A = 0%
Item 67 (Structural Evaluation) =	9
	B = 0%
Item 68 (Deck Geometry) =	9
	C = 0%
Item 69 (Underclearance) =	9
	D = 0%
Item 72 (Appr. Rd. Alignment) =	4
	E = 2%
F = A + B + C + D + E	F = 2%
b. Width of Roadway Insufficiency (15% maksimum)	
$X\ (ADT/\ Lane) = \frac{Item\ 29\ (ADT)}{First\ 2\ digit\ of\ Item\ 28\ (Lanes)}$	
X = 4632	
$Y\ (Width/\ Lane) = \frac{Item\ 51\ (Bridge\ Rdwy.Width)}{First\ 2\ digit\ of\ Item\ 28\ (Lanes)}$	
Y = 6	
If Item 51 (Bridge Rdwy. Width) + 0.6 m < Item 32 (Approach Rdwy. Width) then G = 5%	
6.6 m < 7.8	
(1) Y > 5.5	G = 5%
G + H (15% maximum) = 5%	H = 0%
$S_2 = 30 - [F + (G + H)]$	$S_2 = 23\%$
3. Essentiality for Public Use (15% maximum)	
(1) $K = \frac{S1+S2}{85}$	ADT = 4632
K = 0.9176	Detour = 9.8 km
(2) A = 2.3% (Comparison of ADT and Detour)	
$S_3 = 15 - A$	$S_3 = 12.7\%$
$S_1 + S_2 + S_3$	= 90.7%
4. Special Reductions (Use only with $S_1 + S_2 + S_3 \geq 50$) (13% maximum)	
a. Item 19 Detour Length Reduction (maximum 5%)	A = 5%
b. Item 43 Structure Type	B = 0%
c. Item 36 Traffic Safety Features	C = 1%
$S_4 = A + B + C$	$S_4 = 6\%$
$S_1 + S_2 + S_3 - S_4$	SR = 74.7%

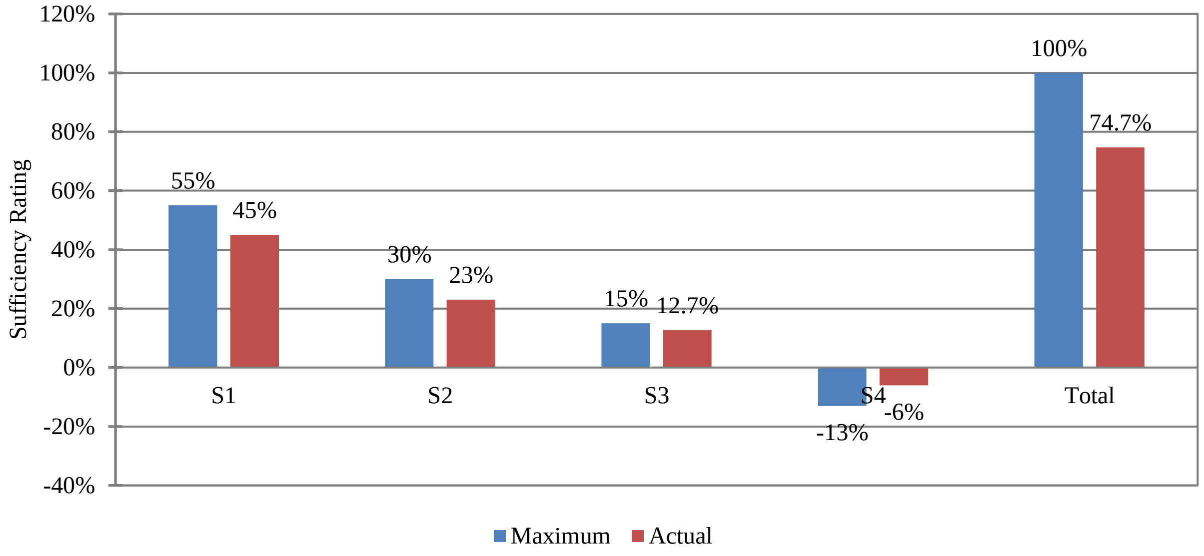

Figure 2. Comparison between maximum and actual value of sufficiency rating

The comparison between the maximum and actual values of the SR calculation is depicted in Figure 2. The results indicate that the S1 parameter shows a percentage difference of 10%. However, the S2 parameter exhibits a 7% difference, signifying a decrease in the bridge's condition value. A greater difference value implies a worsening bridge condition, and vice versa. Additionally, the S3 parameter shows a decrease in value of 2.3%, while parameter S4, the reduction value, exhibits a difference of 7%. This suggests an improvement in the bridge condition as the difference in value increases. The total actual value of the four parameters calculated based on the SR method is 74.7%, with a difference of 25.3% from the maximum value. According to Table 9, with an SR value of 74.7% > 80%, the bridge can be classified as deficient, and further treatment is rehabilitation.

4. Conclusions

Based on the findings of the bridge feasibility assessment conducted using the SR method, it was concluded that this approach proved reliable for decision-making due to its accuracy in evaluating bridge conditions. Despite its complex analysis procedure, the method offered significant advantages by considering many important factors, thereby facilitating long-term monitoring of bridge conditions. Through its careful assessment process, the SR method provided a comprehensive understanding of the structural strength and performance of the bridges under examination.

The SR method has limitations, including a high degree of subjectivity in assessing damage to superstructure and substructure elements. Additionally, detailed assessment of damaged elements is required, which can pose challenges in reaching damaged areas, such as those at height or in areas where highway closure is impractical. With an overall value of 74.7% > 80%, classifying the bridge as deficient and requires rehabilitation treatment, the SR method, encompassing structural adequacy and safety, serviceability, functional obsolescence, and essentiality for public use, demonstrates its efficacy. The findings of the study are expected to provide valuable insights for advancing the development of this method in Indonesia. By contributing to the improvement of bridge assessment practices, these findings have the potential to enhance the efficiency and accuracy of infrastructure evaluation processes.

Acknowledgement

The authors express their sincere gratitude to PT. Jasa Marga Ngawi Kertasono Toll Road Kediri and all parties involved for their cooperation and support throughout the research. Access to the complete bridge detailed visual inspection reports was greatly appreciated as it enhanced the quality of the study by allowing for a comprehensive analysis of relevant data.

References

[1] M. Aflatooni, T. H. T. Chan, and D. P. Thambiratnam, "Condition monitoring and rating of bridge components in a rail or road network by using SHM systems within SRP," *Structural Monitoring and Maintenance*, vol. 2, no. 3, pp. 199–211, Sep. 2015, doi: 10.12989/smm.2015.2.3.199.

[2] Direktorat Jendral Bina Marga (Kementrian Pekerjaan Umum dan Perumahan Rakyat), "Pemeriksaan Jembatan," Jakarta, 2022.

[3] U.S. Department of Transportation (Federal Highway Administration), "The Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridge," Washington, 1995.

[4] E. Puls, M. B. D. Hueste, S. Hurlebaus, and I. Damnjanovic, "Prioritization of a Bridge Inventory for Historic Preservation: A Case Study for Tarrant County, Texas," *Public Works Management and Policy*, vol. 23, no. 3, pp. 205–220, Jul. 2018, doi: 10.1177/1087724X18757533.

[5] M. Stevens and R. Tuchscherer, "Quantifying a Bridge's Structural Resilience," *Practice Periodical on Structural Design and Construction*, vol. 25, no. 4, Nov. 2020, doi: 10.1061/(asce)sc.1943-5576.0000517.

[6] C. Pellegrino, A. Pipinato, and C. Modena, "A simplified management procedure for bridge network maintenance," *Structure and Infrastructure Engineering*, vol. 7, no. 5, pp. 341–351, May 2011, doi: 10.1080/15732470802659084.

[7] J. Weissmann, A. J. Weissmann, and A. Montoya, "Deterioration Models for Texas Bridges and Culverts," *Transp Res Rec*, vol. 2677, no. 7, pp. 307–316, Jul. 2023, doi: 10.1177/03611981231152460.

[8] D. Y. Yang and D. M. Frangopol, "Risk-Informed Bridge Ranking at Project and Network Levels," *Journal of Infrastructure Systems*, vol. 24, no. 3, Sep. 2018, doi: 10.1061/(asce)is.1943-555x.0000430.

[9] A. L. Ramdhani and Sumargo, "Comparison of Condition Rating and Bridge Remaining Life Based on Bridge Management System and Bridge Condition Ratio," *Advances in Engineering Research*, vol. 198, 2020, doi: 10.2991/aer.k.201221.033.

[10] A. Y. Pratiwi, N. Chairunnisa, I. Prasetia, I. F. Radam, and R. Nurwidayati, "Bridge Management System dan Bridge Condition Rating pada Evaluasi Kondisi Jembatan Girder Baja Komposit di Kabupaten Tapin," *Buletin Profesi Insinyur*, vol. 6, no. 1, pp. 26–31, Jan. 2023, doi: 10.20527/bpi.v6i1.180.

[11] S. Inkoom, J. O. Sobanjo, P. D. Thompson, R. Kerr, and R. Twumasi-Boakye, "Bridge health index: Study of element condition states and importance weights," *Transp Res Rec*, vol. 2612, pp. 67–75, 2017, doi: 10.3141/2612-08.

[12] S. Inkoom and J. Sobanjo, "Availability function as bridge element's importance weight in computing overall bridge health index," *Structure and Infrastructure Engineering*, vol. 14, no. 12, pp. 1598–1610, Dec. 2018, doi: 10.1080/15732479.2018.1476561.

[13] A. M. Abdelmaksoud, T. C. Becker, and G. P. Balomenos, "Statistical analysis of bridge management system inspection data," in *20th Congress of IABSE, New York City 2019: The Evolving Metropolis - Report*, International Association for Bridge and Structural Engineering (IABSE), 2019, pp. 898–902. doi: 10.2749/newyork.2019.0897.

[14] M. Taghaddos and Y. Mohamed, "Predicting Bridge Conditions in Ontario: A Case Study," *International Symposium on Automation and Robotics in Construction Journal*, 2019, doi: 10.22260/ISARC2019/0023.

[15] P. Martinez, E. Mohamed, O. Mohsen, and Y. Mohamed, "Comparative Study of Data Mining Models for Prediction of Bridge Future Conditions," *Journal of Performance of Constructed Facilities*, vol. 34, no. 1, Feb. 2020, doi: 10.1061/(asce)cf.1943-5509.0001395.

[16] S. Darban, H. G. Tehrani, N. Karballaeezadeh, and A. Mosavi, "Application of analytical hierarchy process for structural health monitoring and prioritizing concrete bridges in iran," *Applied Sciences (Switzerland)*, vol. 11, no. 17, Sep. 2021, doi: 10.3390/app11178060.

[17] U.S. Department of Transportation (Federal Highway Administration), "Specifications

for the National Bridge Inventory," Washington, 2022.

[18] U.S. Department of Transportation (Federal Highway Administration), "Synthesis of National and International Methodologies Used for Bridge Health Indices," Washington, 2016. doi: 10.13140/RG.2.1.1558.1683.

[19] U.S. Department of Transportation (Federal Highway Administration), "The Impact of Load Rating Methods on Federal Bridge Program Funding FHWA," Washington, 2005.

[20] C. Gui, J. Zhang, J. Lei, Y. Hou, Y. Zhang, and Z. Qian, "A comprehensive evaluation algorithm for project-level bridge maintenance decision-making," *J Clean Prod*, vol. 289, Mar. 2021, doi: 10.1016/j.jclepro.2020.125713.