Structural Relevance as a Criterion for Public Decision-Making in Bridge and Viaduct Rehabilitation

Ana Carvalho, Márcio Buzar, João Pantoja, Huberto Varum

Faculdade de Arquitetura e Urbanismo,
Universidade de Brasília,
Unb, Brasília (70910-900), Brasil

Faculdade de Engenharia da Universidade do Porto,
Universidade do Porto,
R. Dr. Roberto Frias, Porto (4200-465), Portugal

Abstract

The periodic maintenance of bridges and viaducts enables the early identification of damages, facilitating preventive actions, improving the management process, and reducing costs over their service life. However, budget constraints lead to delays, worsening pathological conditions and increasing rehabilitation costs. This study employs a multicriteria method with factor weighting to propose a classification of structural, functional, and durability relevance, in accordance with the ABNT NBR 9452:2023 standard. Inspections conducted on 13 bridges and viaducts in the Federal District identified the structures most in need of intervention, including those located in Taguatinga, Sobradinho, and Candangolândia. The proposed methodology optimizes public management and contributes to governmental efficiency and the safety of road infrastructure.

Keywords: Bridges and Viaducts, Structural Degradation, Periodic Maintenance, Decision Making.

1 INTRODUCTION

Bridges and viaducts are essential elements for transportation and economic development, ensuring regional and national connectivity in a strategic manner (Zhang et al., 2022; Zhao et al., 2021). However, Brazilian road infrastructure faces serious challenges: 66% of the network evaluated by the National Confederation of Transport (NCT) in 2022 was classified as fair, poor, or very poor, which also includes these structures (NCT, 2022). In the Federal District (DF), many bridges and viaducts, built more than six decades ago, exhibit advanced deterioration, including cracks, corrosion, and infiltrations, due to a lack of regular maintenance.

Preventive maintenance is essential to avoid structural collapses and reduce high costs, considering that repairs at advanced stages are substantially more expensive (ASCE, 2020). Early identification of pathologies enables more efficient interventions, promoting greater durability and safety (Soliman et al., 2016).

This study proposes a methodology based on the use of multicriteria methods and factor weighting to identify the relevance of each system (e.g., infrastructure, mesostructure, and superstructure) in compliance with the ABNT NBR 9452:2023 standard. Applied to inspections conducted in the Federal District (DF), the analysis correlates structural, functional, and durability parameters, prioritizing interventions based on objective and technical criteria.

2 LITERATURE REVIEW

This section reviews the literature on urban infrastructure, with an emphasis on the structural design of bridges and viaducts, providing a detailed examination of the systems and elements that comprise them. It also discusses aspects related to the maintenance and inspection of these structures, highlighting the importance of efficient management to ensure their preservation and functionality in the long term. The review further includes the analysis of multicriteria methods and factor weighting applied to the management of bridges and viaducts, as well as the exploration of databases and other tools aimed at enhancing strategic decision-making and improving the efficiency of urban infrastructure maintenance.

2.1 Typology and Impact of Bridges and Viaductson Urban Infrastructure

Urban development and the facilitation of passenger and freight transportation have advanced significantly with the construction of bridges and viaducts, which connected regions previously isolated by natural barriers and boosted economic growth by enabling the flow of goods and people. These structures have played a central role in urban expansion, establishing the necessary infrastructure to support population and economic growth. DNIT (2004) defines a bridge as "a structure built over an obstruction, supporting a roadway for the passage of vehicles and other moving loads, with a free span of more than six meters." Valeriano (2021) highlights the importance of distinguishing passage structures based on the obstacle to be overcome and the project's function.

The typology of bridges and viaducts involves selecting methods and materials based on terrain, span length, expected load, and environmental conditions. Bridges can be arch or suspension types, while viaducts generally use beams or trusses, offering different advantages in terms of cost, durability, and environmental impact, making the choice of typology crucial in the planning and execution of these projects.

2.2 Classification and Structural Components

According to Valeriano (2021), the structural elements of bridges and viaducts can be subdivided into four main categories: (i) **Primary structural elements**, such as the superstructure, mesostructure, and infrastructure, which are responsible for load support and distribution; (ii) **End structural elements**, such as retaining walls and abutments, which ensure the stability of the extremities; (iii) **Support elements and systems**, made of reinforced concrete, steel, or elastomers, which transfer loads from the superstructure to the foundation; and (iv) **Protection and safety elements**, such as guardrails and barriers, designed to protect users and ensure the structure's safety.

Amorim D. (2012) subdivides the structure of a bridge into three interdependent systems: the superstructure, mesostructure, and infrastructure. Similarly, the NBR 9452:2023 standard categorizes the main components of a structure into three groups:
(i) **Superstructure**, which supports vertical loads and transfers them to the mesostructure;
(ii) **Mesostructure**, which supports the superstructure and transfers its loads to the infrastructure; and
(iii) **Infrastructure**, comprising foundation elements responsible for transferring loads to the ground, ensuring the structure's stability.

2.3 Maintenance and Inspection

The maintenance of bridges and viaducts is essential to ensure the preservation and integrity of these structures. DNIT (2016) defines maintenance as a set of activities aimed at preserving the structure and ensuring its proper use. These works are constantly subject to wear and tear from continuous use and weather exposure, and the absence of preventive programs accelerates their degradation. Regular inspections are fundamental for preserving the durability and functionality of these structures (ARAÚJO, 2014).

According to Ferreira (2018), the service life of a bridge or viaduct depends on continuous monitoring, which is essential for planned maintenance. NBR 15575:2013 emphasizes the importance of maintenance to ensure compliance with the established performance levels. The Bridge and Viaduct Maintenance Manual (DNIT, 2016) highlights that the conservation of these structures is one of the most critical tasks for responsible agencies. Periodic inspections are necessary to detect defects that may compromise structural integrity (Zanini et al., 2017).

According to Santarsiero et al. (2021), regulations classify inspections into three types: cadastral, routine, and extraordinary, with routine inspections conducted annually. These are essential for assessing the evolution of previous anomalies and identifying new issues. NBR 9452:2023 classifies bridges and viaducts based on structural, functional, and durability parameters, assigning ratings ranging from excellent to critical, reflecting the severity of identified problems, as presented in Table 1.

Grade	Condition	Structural Characterization	Functional Characterization	Durability Characterization
5	Excellent	The structure is in satisfactory condition, with only minor and isolated defects.	Provides safety and comfort to users.	In perfect condition; routine maintenance should be scheduled.
4	Good	The structure shows minor damage without compromising structural safety.	Shows minor damage that does not cause discomfort or safety concerns for users.	Exhibits minor anomalies affecting its useful life in areas with low environmental aggressiveness.
3	Fair	There are damages that could lead to structural deficiencies, but no signs of stability compromise.	Causes discomfort to users, with defects that require medium-term corrective actions.	Displays few but noticeable anomalies affecting its useful life, particularly in areas with moderate to high environmental aggressiveness.
2	Poor	Damage compromises structural safety, though without immediate risk of collapse.	Functional capacity is visibly compromised, presenting safety risks for users.	Exhibits moderate and widespread anomalies that significantly impact its useful life, especially in highly aggressive environments.
1	Critical	Severe structural deficiencies exist, with some elements in critical condition and a tangible risk of collapse.	Does not meet functional conditions for safe use.	The structure is highly deteriorated, indicating serious structural and functional risk

Table 1 Adapted from ABNT NBR 9452 (2023)

2.4 Management and Costs

In the 1980s, the increasing degradation of reinforced and prestressed concrete structures raised concerns about safety and maintenance costs, highlighting the importance of preservation throughout the service life of these structures (BERTOLINI, 2010). Zhang et al. (2022) point out that bridge collapses are often related to factors such as regional economy, structural type, material, usage, and age.

Similarly, Vitório (2007) attributes failures to the lack of continuous monitoring and periodic maintenance, as evidenced by cases of bridge collapses in Brazil between 1990 and 2005. This reflects the absence of a preventive maintenance culture, which leads responsible agencies to prioritize new construction over preservation, resulting in the visible deterioration of bridges and viaducts. The lack of structured conservation policies compromises safety entails high repair costs, and negatively impacts society.

In this context, Sitter's Law (1984), illustrated in Figure 1, demonstrates that maintenance costs increase exponentially over time, making repairs more complex and expensive. Therefore, managing these structures requires a continuous inspection program, as highlighted by Verly (2015), who emphasizes the need to allocate more resources for the maintenance and rehabilitation of these works.

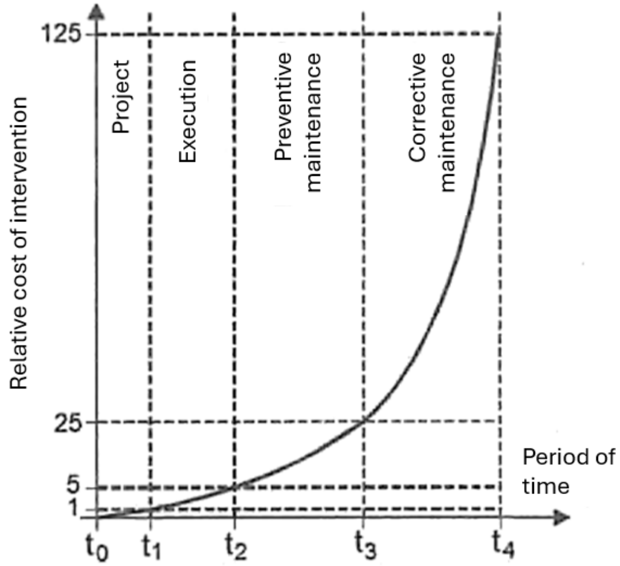

Fig. 1 Adapted from SITTER, 1984.

2.5 Multicriteria Method, Statistics, and Weighting Factors

The need for specialized diagnostics and quick decisions for preventive maintenance of bridges and viaductshas led to multicriteria methods standing out as effective tools for solving problems with conflicting criteria (BRANS & MARESCHAL, 2005). Vincke (1992) emphasizes that these methods are advantageous because they seek the most suitable alternative, considering the weighting of the data. The main difference compared to other approaches is the simultaneous consideration of multiple aspects, using mathematical functions to measure the performance of each action (ENSSLIN, 2001).

Among these methodologies, factor weighting stands out, which assigns importance to defined criteria, allowing for the evaluation and comparison of alternative solutions (PEDRYCZ; EKEL; PARREIRAS, 2011; EKEL; PEDRYCZ; PEREIRA, 2020). In the statistical context, the weighted arithmetic mean is used to indicate the typical value of a distribution, considering the weights assigned to each data point, thereby increasing the relevance of values with higher weights. The calculation is performed by multiplying each value by its weight, summing the products, and dividing by the sum of the weights, as follows:

$$Xp = \frac{X_1 \text{ x } P_1 + X_2 \text{ x } P_2 + X_3 \text{ x } P_3 \ldots + X_n \text{x } P_n}{P_1 + P_2 + P_3 \ldots + P_n} \quad (1)$$

3 METHODOLOGY

The development of factors for decision-making in the maintenance of bridges and viaductsrequired practical immersion in the daily routine of inspections, with direct contact with the responsible parties and detailed analysis of all stages of the process. The routine inspection methodology follows ABNT NBR 9452:2023, which includes: an introduction with basic information, classification of the bridges and viaducts (Operational and Structural Condition), comments on changes in the general condition, an inspection form with records of anomalies, photos, and other relevant information.

The inspection form classifies bridges and viaductsbased on structural, functional, and durability parameters, assigning ratings from excellent to critical, as per item 3.1.2 of the standard. The maintenance decision is based on these classifications; however, the process can be time-consuming due to the large number of technical reports. Therefore, optimizing decision-making processes, along with a solid strategic plan, becomes crucial to address the challenges inherent in bridge and viaducts maintenance management, thus ensuring the safety and efficiency of these structures vital for urban mobility. The next sections will detail the weighting factors proposed and analyzed in the study in question.

3.1 Factors influencing decision-making

For the methodological development of this work, the relevance factor (Equation 2), the general classification factor (Equation 3), and the classification factor of the elements (Equation 4) were considered, based on the application of the multicriteria method and the factor weighting technique, using weighted arithmetic means as an analysis tool, as presented in the following equations.

- Relevance Factor (FR): Equation that weighs the general and structural factor based on each evaluated structure.

$$F = \frac{(F_G + F_E)}{2} \quad (2)$$

General Classification Factor (FG): It consists of the weighted arithmetic mean of the structural, functional, and durability parameters defined in ABNT NBR 9452:2023.

$$F_G = \frac{N_E \times P_E + N_D \times P_D + N_F \times P_F}{P_E + P_D + P_F} \quad (3)$$

In the context of the General Classification Factor (FG), the weighting of the weights assigned to the "P" variables in Equation 3 was defined in accordance with the Bridge, Overpass, and Pedestrian Bridge Inspection Standard (ABNT NBR, 2023). This standard establishes a hierarchy among the structural, durability, and functional factors, assigning greater relevance to the structural factor due to its importance for the integrity and safety of the structure.

Thus, the structural conditions of the viaducts must be evaluated and, when necessary, prioritized for intervention. The durability factor is then considered to ensure the longevity of the structure. Lastly, the functional factor is analyzed to ensure that the viaducts adequately meet its operational functions.

According to the classification criteria for the condition of bridges and viaducts (presented in Table 1), the ratings assigned to the "N" variables in Equation 3 can range from 1 to 5. Based on these criteria, Table 2 presents the proposed weights assigned to the importance level of each factor fmor the classifications defined in the aforementioned standard.

Parameter	Weight (P)
Structural	1.00
Durability	0.75
Functionality	0.50

Table 2 Importance factor for the classification of the parameters defined according to ABNT NBR 9452 (2023)

Classification Factor of the Elements (FE): It consists of the weighted arithmetic mean of the evaluated structural elements (e.g., Superstructure, Meso-structure, Infrastructure, Bearings, Safety and Drainage Elements and Accessories), as defined in ABNT NBR 9452:2023.

$$F_E = \frac{N_1 \times P_1 + N_2 \times P_2 + N_3 \times P_3 \ldots + N_n \times P_n}{P_1 + P_2 + P_3 \ldots + P_n} \quad (4)$$

The weighting of the data for the General Classification Factor of Elements (FE) was based on the importance of each element to the structural safety of bridges and viaducts, as outlined in ABNT NBR 9452:2023. The main elements (P), whose failure could lead to partial or total collapse, have the highest relevance; secondary elements (S), whose damage may result in localized failures, hold intermediate importance; and complementary elements (C), whose failure affects only the functionality of the structure, are assigned lower priority.

This standard establishes clear criteria for prioritizing elements within the structural system, assigning scores to elements based on the aggregation of the structures associated with each evaluated component.

For example, the scores for the "N" variables of crossbeams, columns, and bearings were weighted to calculate the average for the mesostructure, as these elements form its composition.

Following this logic, the infrastructure and mesostructure are assigned the highest level of importance, while complementary elements are categorized with lower priority. The weights assigned to the "P" variables were determined based on a sensitivity analysis described in ABNT NBR 9452:2023. Table 3, therefore, presents the definition of importance factors, considering the distribution and relevance of structural elements.

Structure	Weight (P)
Infrastructure	1.00
Meso-structure	1.00
Superstructure	0.75
Connections	0.50
Safety Elements and Accessories	0.25
Drainage	0.25

Table 3 Importance factor of structural elements defined according to ABNT NBR 9452 (2023)

3.2 Applicability of the methodology

To validate the proposed methodology, 13 inspection reports of bridges and viaducts under the responsibility of the Federal District Department of Roads (DER/DF) were analyzed. Conducted between September and December 2022, the inspections included structures such as the Bridge over the Urubu River, the Viaduct on DF-003, and the Bragueto Central Bridge, covering a variety of typologies and locations, ranging from bridges over rivers and streams to viaducts on busy highways.

It is worth noting that two of the reports (numbered 029 and 031) did not include a general evaluation of the structure during the respective inspections. To preserve the integrity of the data analysis, these samples will be excluded from the scope. Consequently, the data presented in the results will derive from the 11 reports that provided consistent parameters for the analysis in question.

4 RESULTS

Finally, the proposed method was applied to evaluate the performance of the Relevance Factor in decision-making. The results obtained from the analysis of the eleven inspection reports are detailed in Table 5, while Figure 2 presents the correlation of the proposed factors.

Report	Typology	Location	FG	FE	FR
001	Bridge	Bridge over Rio Urubu	2.78	3.60	3.19
004	Viaduct	Viaduct 1 on DF003	2.78	3.09	2.94
010	Bridge	Bridge 2 over Ribeirão do Torto	3.22	3.72	3.47
019	Viaduct	Viaduct 1 over DF-003 on DF-085	2.00	3.17	2.59
020	Viaduct	Viaduct 2 over DF-003 on DF-085	1.67	2.49	2.08
027	Bridge	Bridge 2 over Ribeirão Sobradinho	1.67	2.78	2.23
100	Viaduct	Viaduct to Candangolândia	1.78	2.93	2.36
200	Bridge	Bridge over Rio Jardim on DF-260	2.56	3.47	3.02
631	Bridge	Bragueto Bridge Eixo W	3.56	3.88	3.72
632	Bridge	Bragueto Bridge Eixo L	2.78	3.92	3.35
659	Bridge	Central Bragueto Bridge	2.67	3.39	3.03

Table 5 Results of the Proposed Factors Through the Inspection of Bridges and Viaducts in the Federal District

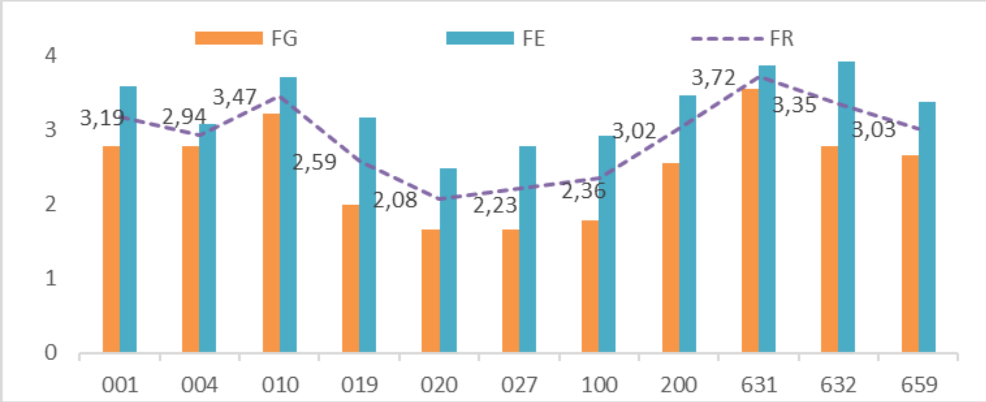

Fig. 2 Correlation of Factors

The application of the proposed method demonstrated consistency in evaluating the most critical inspection reports (reports 020, 027, and 100), corresponding to the regions of Taguatinga, Sobradinho, and Candangolândia. Photographic records revealed pillars with disaggregated concrete and exposed reinforcements, slabs with ruptures in positive reinforcements and vehicle impact signs, as well as guardrails with cracks.

hese areas exhibit characteristics that intensify structural wear. Taguatinga, with approximately 210,000 inhabitants, experiences heavy traffic due to its commercial density and public transportation activity. Sobradinho, home to 140,000 residents, hosts the BR-020, a strategic regional connection route, while Candangolândia, with 40,000 inhabitants, is located at a critical access point to the capital. These factors, supported by data from IBGE (2022), underscore the need for regular maintenance to ensure structural safety.

The Relevance Factor, as presented in the results, aims to align normative parameters and support decision-making without replacing the necessity of a qualified professional to conduct inspections and assessments. Specialized technical expertise remains indispensable for ensuring the accuracy and integrity of evaluations, preventing accidents, and promoting the functionality of critical infrastructure.

5 CONCLUSION

Special works of art, such as bridges and viaducts, are essential pillars for economic development and urban mobility, requiring continuous maintenance to ensure their safety and durability (Zhang et al., 2022; Zhao et al., 2021). In this context, the Relevance Factor proposed in this study emerges as a strategic tool to support public management in prioritizing interventions and efficiently allocating resources.

The presented approach enables an objective assessment of structural conditions, based on current regulations such as ABNT NBR 9452:2023. The results obtained demonstrated consistency with DER/DF reports, reinforcing the method's validity and practical applicability. Furthermore, by linking the Relevance Factor to a risk matrix, it was possible to highlight structures requiring immediate attention, optimizing maintenance decisions.

Finally, the implementation of this methodology not only strengthens the effective management of SOAs but also promotes public safety and the sustainability of urban infrastructure. The adoption of practices based on data and regulations contributes to preserving public assets and ensures the functionality of structures vital to society.

References

[1] AMERICA SOCIETY OF CIVIL ENGINEERS - ASCE. Report Card of America's Infrastructure. 2020.

[2] AMORIM D. Técnica de analogia de grelha associada a um modelo de pórtico para análise do comportamento de sistemas estruturais de pontes. 2012.

[3] ARAÚJO C. Vistoriando obras de arte especiais. Revista notícias da construção. 2014. https://issuu.com/sind_issuu/docs/revista_ed_138_web. Accessed August 02, 2024.

[4] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). ABNT NBR 9452. Vistoria de pontes e viadutos de concreto, Rio de Janeiro, 2023.

[5] _____. ABNT NBR 15575. Edificações habitacionais — Desempenho Parte 1: Requisitos gerais. Rio de Janeiro, 2013.

[6] CONFEDERAÇÃO NACIONAL DO TRANSPORTE - CNT. Rodovias brasileiras apresentam piora de qualidade. 2022. https://cnt.org.br/agencia-cnt/rodovias-brasileiras-apresentam-piora-de-qualidade. Acesso em: 17 de maio de 2023.

[7] CORREIO BRAZILIENSE - CB. Atenção aos viadutos do DF. 2021. https://www.correiobraziliense.com.br/cidades-df/2021/10/4957173-atencao-aos-viadutos-do-df.html. Accessed August 22, 2024.

[8] _____. Diretoria Executiva. Instituto de Pesquisas Rodoviarias. Manual de recuperação de pontes e viadutos rodoviários. 159p. (IPR. Publicacao, 744). Rio de Janeiro, 2016.

[9] FERREIRA. Inspeção e monitoramento de obras de arte especiais com vista a manutenção preditiva. 2018. 117 f. TCC (Graduação) - Curso de Engenharia Civil, Escola Politécnica.

[10] SANTARSIERO, G., MASI, A., PICCIANO, V., e DIGRISOLO, A. The Italian guidelines on risk classification and management of bridges: Applications and remarks on large scale risk assessments. Infrastructures. 2021.

[11] SITTER. Lei da Evolução de Custos ou Lei de Sitter. 2024. https://www.guiadaengenharia.com/lei-custos-sitter/. Accessed January 07, 2024.

[12] VALERIANO ALVES, R. Pontes. In: Oficina de Textos - 1a Edicao. ISBN:9786586235173. 2021.

[13] VERLY, R. C. Avaliação de Metodologias de Inspeção como Instrumento de Priorização de Intervenções em Obras de Arte Especiais.198p.. Universidade de Brasília. 2015.

[14] ZHANG, G., LIU, Y., LIU, J., et al., 2022. Causes and statistical characteristics of bridge failures: a review. Journal of Traffic and Transportation Engineering (English Edition) 9 (3), 388e406.

[15] ZHAO, T., GOU, H., CHEN, X., ET AL., 2021. State-of-the-art review of bridge informatization and intelligent bridge in 2020. Journal of Civil and Environmental Engineering 43 (S1), 268e279.

[16] ZANINI ET AL. Bridge residual service-life prediction through Bayesian visual inspection and data updating. Structure and Infrastructure Engineering. 2017.