

Monitoring steel bridge degradation with multi-criteria approaches

Mostefa Lallam^a, Abdelkader Djebli^b

^a Mustapha Stambouli University, Department of Civil Engineering, Mascara, People's Democratic Republic of Algeria + Laboratory Mechanics of Structures, University of Tahri Mohamed, Bechar, People's Democratic Republic of Algeria
e-mail: m.lallam@univ-mascara.dz, **corresponding author**,
ORCID iD: <https://orcid.org/0000-0002-0022-6646>

^b Mustapha Stambouli University, Department of Mechanical Engineering, Mascara, People's Democratic Republic of Algeria + Laboratory of Mechanics of Materials, Energy and Environment (L2M2E), Mascara, People's Democratic Republic of Algeria
e-mail: djebliabdelkader@univ-mascara.dz,
ORCID iD: <https://orcid.org/0000-0001-9102-2202>

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Abstract:

Introduction/purpose: The objective of this work is to formulate a Fuzzy Analytical Hierarchy Process (FAHP) method that can assist specialists in conducting inspections of steel bridges. Fuzzy logic approaches are preferred due to their ability to handle uncertain information in ways that mirror human reasoning processes, making them particularly suitable for structural damage assessment applications.

Methods: The procedure is organized in a hierarchical framework consisting of 35 criteria and sub-criteria. This structure is designed to assist the project's inspection stakeholders in making decisions. The weights W_i of these criteria are established by utilization of the FAHP, supplemented by expert evaluations, in order to compute the comprehensive performance indicator CPI score that represents the extent of damage to the bridge being examined. The structure is categorized based on its overall CPI score using the IQOA notation.

Results: To rigorously evaluate the practical applicability and accuracy of the developed FAHP methodology, a real-world case study was undertaken. The methodology was applied to assess the health condition of the steel bridge situated in Oued Taria, located within the Mascara region. The application of this comprehensive approach yielded results that demonstrated remarkable consistency and strong alignment with previous, independently conducted expert assessments of the same structure.

Conclusion: The successful application and validated results unequivocally affirm the scientific efficacy and practical utility of this FAHP-based tool. It

serves as a robust and reliable decision-support system, significantly enhancing the capabilities of experts in accurately assessing the complex and often subjective aspects of damage in steel bridges. This methodology not only streamlines the inspection process but also contributes to more objective and consistent evaluations, ultimately leading to improved maintenance planning and enhanced safety of critical bridge infrastructure.

Key words: steel bridges, Fuzzy Analytical Hierarchy Process (FAHP), comprehensive performance indicator (CPI).

Introduction

Throughout their lifespan, steel bridges are subjected to a multitude of loads that progressively compromise their initial structural integrity. These loads can be of various types: permanent loads exerted by the self-weight of the structure and the elements it supports, dynamic loads induced by traffic, accidental loads such as impacts or exceptional overloads, and natural loads related to meteorological phenomena. The accumulation of damage due to traffic loads, especially from overweight trucks, significantly affects the durability of steel bridge components, necessitating detailed studies to assess these impacts (Cha et al., 2016; Wang, Deng & Shao, 2016). Additionally, the randomness of traffic loads can lead to increased fatigue in bridge elements, particularly in wide bridges with high vehicle velocity (Wysocki, 2020). Environmental factors, including corrosion and climate change, further exacerbate the degradation of steel bridges, impacting their load-carrying capacity and structural integrity (Gocal & Odobinak, 2020; Palu & Mahmoud, 2019). Extreme events, such as blasts, also pose significant risks, potentially leading to local damage or progressive collapse of the structure (Olmati et al., 2013; Tetougueni, Zampieri & Pellegrino, 2020). Therefore, it is crucial to consider these various load types and their cumulative effects when evaluating the structural performance and longevity of steel bridges. In light of these limitations, the Fuzzy Hierarchy Analysis Process (FAHP) is a robust method for efficiently assessing and classifying the overall damage level of bridges. This approach integrates the traditional Analytic Hierarchy Process (AHP) with fuzzy logic to handle the inherent uncertainties and subjective judgments involved in evaluating complex structures. For instance, the FAHP method has been successfully applied to assess corrosion damage in reinforced concrete bridges by combining various factors such as the Corrosion Damage Index, Environmental Change Factor, and Material Vulnerability Factor, thereby providing a comprehensive damage evaluation (Gao & Li, 2018). Similarly, the FAHP method has been utilized in the risk assessment of bridges during

construction, demonstrating its effectiveness in identifying and ranking diverse risk factors through a fuzzy logic-based approach (Cheng, Xu & Chen, 2019). Moreover, the improved FAHP method, which introduces reliability into the judgment matrix, has been shown to enhance the precision of evaluations for large-span concrete cable-stayed bridges by addressing the fuzziness of subjective judgments (Li & Qu, 2023). The application of FAHP in the maintenance programming of masonry arch bridges further underscores its versatility, as it allows for the classification of degradation states based on a multitude of criteria and sub-criteria, ensuring a systematic and reliable assessment (Lallam, Mammeri & Djebli, 2021). Furthermore, the hierarchical nature of FAHP enables a thorough analysis of criteria, which aids in making well-informed decisions regarding damage assessment (Lallam, Djebli & Mammeri, 2023). Within the same framework, Fuzzy Analytic Hierarchy Process (FAHP) is a very effective method for determining and classifying the degree of damage in steel bridges. Research indicates that FAHP can quantitatively assess safety conditions by integrating various monitoring data, such as stress, deformation, and environmental factors, which are critical for understanding structural integrity (Yang et al., 2024; Su et al., 2024). The method's ability to handle uncertainties and subjective judgments enhances its applicability in complex evaluations, as demonstrated in studies on both steel box girder bridges and concrete cable-stayed bridges (Li & Qu, 2023; Liu et al., 2023). The study devised a Fuzzy Analytical Hierarchy Process (FAHP) to assist specialists in conducting steel bridge inspection campaigns. The approach has 35 criteria and sub-criteria, with weights derived by FAHP. The comprehensive performance indicator CPI score is categorized using IQOA notation. The methodology was utilized on the Oued Taria steel bridge, validating its efficacy in evaluating reinforced concrete bridges.

Steel girder bridges: a structural overview

Steel-girder bridges are a popular choice for transportation infrastructure, primarily relying on steel girders for support construction. These horizontal structural elements extend between two abutments or piers, supporting the load of the bridge deck. Steel girder bridges are known for their durability and longevity, making them ideal for heavily frequented highways and seismic regions. Engineers can construct steel girder bridges in straight, curved, or skewed alignments, typically for long spans with shallow depths. As shown in Figure 1, the main components of a steel girder bridge include girders, the deck, abutments, bearings,

expansion joints, a drainage system, access points, lighting, and guardrails.

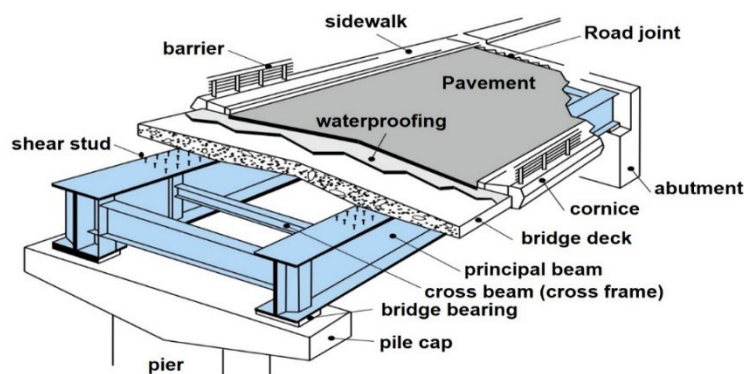


Figure 1 – Steel girder bridge

Case study: Oued Tagia steel bridge

Geographical location

The object of the study is a bridge located at kilometer point 74+900, across the Oued Tifrit on National Road NR 06. The site is situated at the entrance of the city of Taria in the wilaya of Mascara, located in the north-western part of Algeria. The GPS coordinates are as stated: they correspond to a latitude of 35.1138°N and a longitude of 0.082°E . Due to its favorable geographical location, this bridge serves as a vital thoroughfare for both local residents and tourists in the region. Figure 2 illustrates the precise geographic coordinates of this bridge, which was built using a steel framework.

GPS coordinates : Latitude : $35^{\circ}06'49.7''\text{N}$ Longitude : $0^{\circ}04'55.2''\text{E}$



Figure 2 – Satellite view of the bridge as shown on Google Maps

Description of the bridge

Figure 3 depicts a comprehensive perspective of the bridge from a downstream vantage point. The assessment pertains to a structure situated in a linear configuration along National Route NR 06, crossing Oued Tifrit at KP 74+900.

Regarding the framework, the bridge superstructure consists of three main steel girders with solid webs. These girders are of the Welded Built-Up Section (WBS) type, thereby allowing them to be optimized for the 30-meter span of the bridge. Furthermore, a system of truss cross-beams reinforces the longitudinal girders, with three bracing beams placed in the middle of the span and two at each end for enhanced stability.

Moving on to the deck, it is a composite steel-concrete system with a thickness of 20 cm. Crucially, it is not merely resting on the girders; instead, it is made integral with the upper flange of each steel girder. This connection is ensured by shear connectors (studs) welded to the top flange of the girders. This design ensures composite action, where the concrete slab and steel girder work together to resist bending stresses, consequently increasing the efficiency and load-bearing capacity of the structure.

Moreover, the main structural system of the bridge is that of a simply supported beam. This design allows for a simple and direct transfer of loads to the abutments, without significant bending moments at the supports. The bridge rests on two massive reinforced concrete abutments, which are protected by gabions and reinforced with wing walls.



Figure 3 – Panoramic view downstream from the bridge

Summary of bridge damages

The bridge in question holds a crucial strategic position, serving as a vital link between the wilayas of Mascara and Saida along the national road NR06. As a result, it experiences heavy traffic and serves as an essential crossing point for both local residents and visitors to the region. Our on-site inspection, as illustrated in Figure 4, revealed a range of concerning damage types. Despite being constructed in the early 1980s according to preliminary information - a relatively recent timeframe that should suggest better condition - the bridge's health status contradicts expectations.



Figure 4 – Images depicting the extent of bridge damage: a) intrados of a cantilevered slab, b) abutment 02, c) main beams, d) cross frame, e) pavement, f) barrier

The inspection uncovered several critical issues: localized concrete spalling with exposed corroded reinforcement, water seepage marks, and efflorescence on the underside of the deck slab and abutments, as shown in Figures 4 (a-c). Furthermore, pronounced rust was clearly observed on the lower flanges of the steel girders and at the crossbeam joints; see Figures 4 (a-d). The road surface hasn't escaped damage either, with Figures 4 (e-f) showing cracking of the deteriorated pavement. The guardrails are in a particularly poor state, with detached, deformed, and generally deteriorated posts. These multiple issues, spanning various components of the bridge structure, indicate a pressing need for comprehensive maintenance and potential rehabilitation to ensure the continued safety and functionality of this important infrastructure asset.

FAHP-based procedure for evaluating the degradation of steel bridges

In order to evaluate the level of degradation of older steel bridges, this work intends to construct a numerical model using the Fuzzy Analytical Hierarchy Process (FAHP) approach. Figure 5 shows the five steps that make up the suggested flowchart. First, determine the causes of bridge deterioration and its hazards. Next, we build the hierarchical structure of the model. We use the FAHP approach to set up this structure and determine the weightings of the factors and sub-factors, as we will explain later. The next phase computes a comprehensive performance indicator (CPI) to classify the degree of degradation of the steel bridge in the final stage.

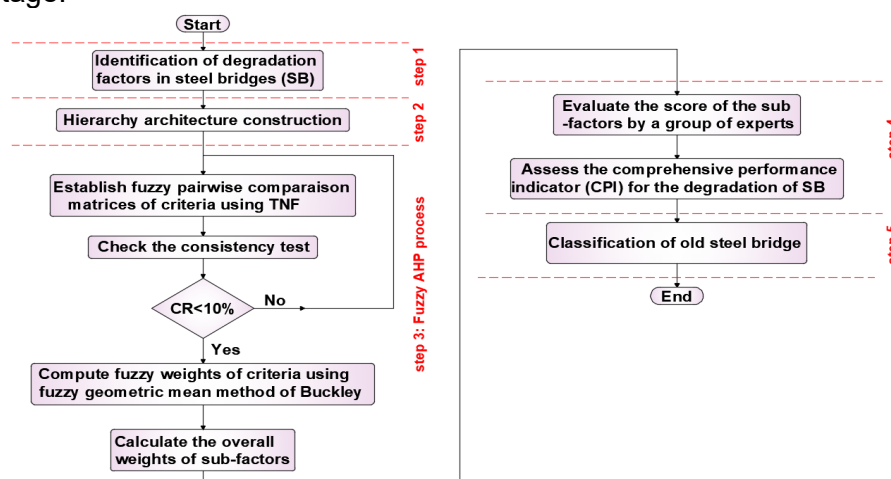


Figure 5 – Procedure flowchart for assessing the degradation of steel bridges

Identifying degradation factors and creating the hierarchical structure

The developed methodology demonstrates broad applicability to different types and structural systems of bridges, as evidenced by our practical experience on masonry road bridges (Lallam, Mammeri & Djebli, 2021) and reinforced concrete bridges (Berrekheroukh et al., 2025), as well as its potential extension to pedestrian bridges and steel or composite steel-concrete structures. The fundamental principles of our approach are sufficiently flexible to adapt to these various structural configurations, with the required adaptations primarily focusing on adjusting the criteria and sub-criteria for assessing the degree of degradation based on the specificities of each case study. The structural system, including the support configuration (simply supported beams, continuous beams, etc.), indeed constitutes a determining factor that our methodology integrates during the scoring of criteria related to the load-bearing elements of the analyzed bridge, thus enabling an assessment adapted to the specific mechanical and behavioral characteristics of each structure.

The methodology for calculating the model begins with a crucial step: identifying and selecting factors likely to influence the degradation of the structure. This initial phase is of paramount importance as it lays the foundation for all subsequent analysis. To ensure the comprehensiveness and relevance of this selection, a dual approach is adopted. On the one hand, a thorough examination of specialized literature is conducted, allowing for the identification of factors recognized by the scientific community as significant in the bridge degradation process. This literature review provides a solid base, grounded in theoretical and empirical knowledge accumulated over the years by researchers and practitioners in the field. On the other hand, this foundation is enriched and refined through valuable advice from industry experts. Their practical experience and in-depth understanding of the specific challenges related to civil engineering structures allow for the adjustment of factor selection based on real-world considerations. Once this first step is completed, the procedure continues with the development of the model's hierarchical structure, illustrated in Figure 6. This structure forms the backbone of the evaluation model and organizes in a logical and coherent manner the criteria and sub-criteria identified as having the most significant impact on the degradation of steel bridges. This hierarchization not only allows for a clear visualization of the relationships between different factors but also prepares the ground for the subsequent application of the FAHP method, which requires a well-defined structure for the attribution of weightings.

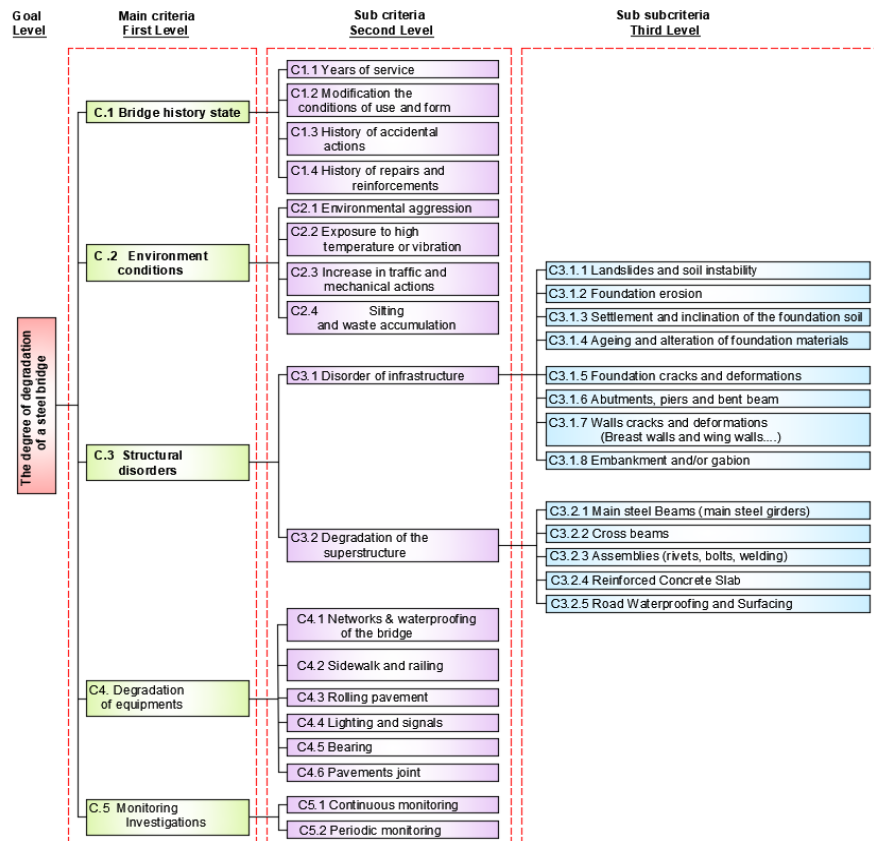


Figure 6 – The established evaluation criteria hierarchy

Calculating weighting coefficients: the FAHP method in practice

Triangular fuzzy numbers (TFN): an overview

We have decided to include triangular fuzzy numbers (TFN) within the FAHP technique framework to handle the inherently uncertain and ambiguous aspects of our study. Because it is simple to numerically implement, this method is preferred by many researchers. The three values that define a TFN are 'a' for the lower limit, 'm' for the middle point, and 'u' for the upper limit. The membership function of a TFN is illustrated graphically in Figure 7. Our study's examination of complicated parameters is greatly enhanced by this method, which enables more accurate modelling of uncertain or imprecise data. We are able to successfully

detect and quantify minute differences and nuances that may escape a classical method by incorporating TFNs into the FAHP process.

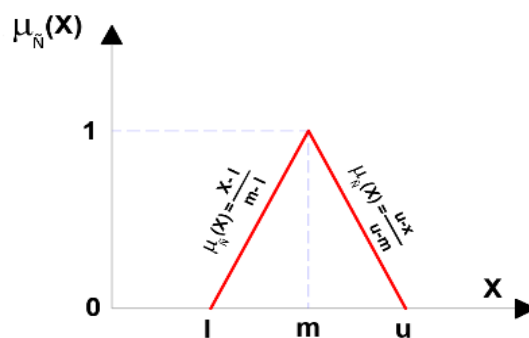


Figure 7 – Graphical illustration of TFN

The conventional comparative scale

The choice of a suitable triangular fuzzy number (TFN) is determined by a comprehensive analysis carried out by our team of experts. This approach entails the simultaneous assessment of two crucial criteria, the relative significance of which varies depending on the specific goals of the study. Figure 8 provides a comprehensive depiction of the intricate procedure involved in making this conclusion. The experts must exhibit profound discernment in order to achieve the optimal equilibrium between these two criteria, both of which exert a significant impact on the relevance of the selected TFN. This two-dimensional approach guarantees that the chosen TFN is the best fit for the unique requirements of our research project. The researchers' specialized knowledge is essential for negotiating the intricacies of this process and making a selection that accurately represents the subtleties and uncertainties inherent in our field of study.

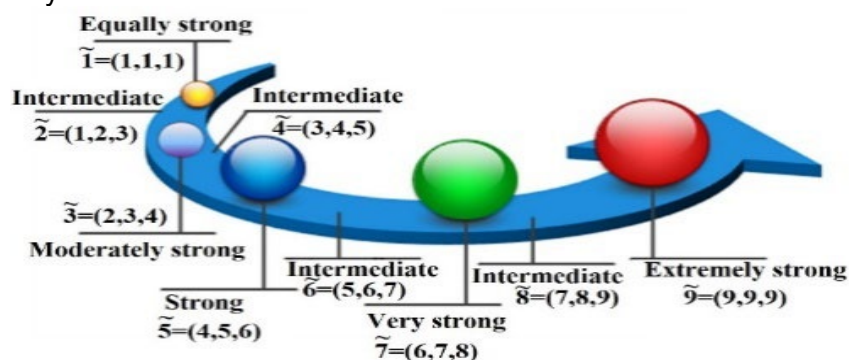


Figure 8 – Evaluation scale for criteria in terms of TFNs

Fuzzy geometric mean method (FGMM)

Figure 9 is a flowchart illustrating the steps involved in implementing a Fuzzy Analytic Hierarchy Process (FAHP). The approach commences by generating matrices for pairwise comparisons, utilizing triangular fuzzy integers to represent uncertain judgements. We subsequently convert the imprecise numbers into exact values to streamline computations. Next, we perform a consistency check to confirm the reliability of the pairwise comparisons. The procedure involves calculating the fuzzy geometric mean and weights, which are then defuzzified and normalized. The FAHP approach provides a systematic framework for effectively managing uncertain information and prioritizing options based on multiple criteria. This refers to Table 1, which is part of the flow chart.

Table 1 – Random coherence index (RI)

n	3	4	5	6	7	8	9	10
RI	0.525	0.882	1.109	1.248	1.342	1.406	1.450	1.485

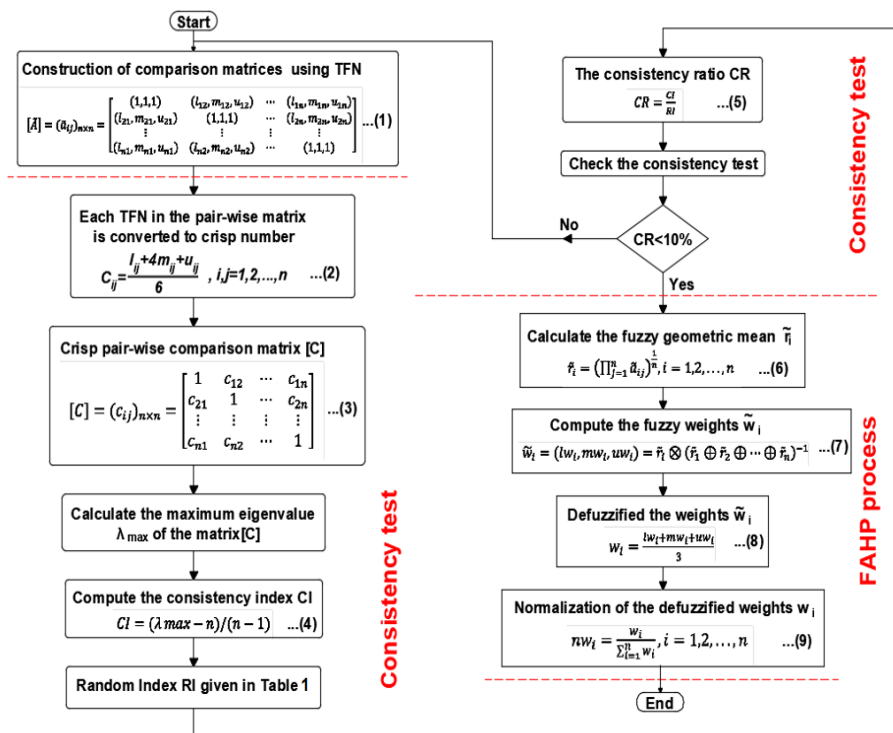


Figure 9 – A flowchart that demonstrates the process of calculating weight using the fuzzy geometric mean method

Assessment of expert rating (ER)

The FAHP approach is employed in this section of the study to ascertain the relative weights of each element. Afterwards, experts award an intersectional functioning index (ER) to each element, ranging from 0 to 10. This index represents the comparative significance of each component in assessing the efficient operation of the intersection. Table 2 displays the relationship between the 'ER' and its equivalent scale.

Table 2 – Status of risk scale

ER	State condition of scaling
[0,2]	no risk grade noticed
[2,4]	low- grade risk
[4,6]	moderate risk
[6,8]	high risk
[8,10]	super high risk

The collective expert assessment (CEA) is derived using the following equation:

$$CEA_i = \frac{\sum_{j=1}^m ER_j}{m}, \quad (1)$$

where m signifies the total number of participating specialists in the evaluation process.

To conclude, the comprehensive performance indicator (CPI), which represents the overall operational effectiveness of the intersection under scrutiny, is mathematically expressed as:

$$CPI = \sum_{i=1}^K w_i \times CEA_i, \quad (2)$$

In this formula, i ranges from 1 to k , where k denotes the number of sub-factors chosen for analysis.

Steel bridge classification and degradation as stated by IQOA

The IQOA (Lallam, Djebli & Mammeri, 2023) is a standardized assessment method in France for evaluating bridge condition. It identifies deteriorations and assigns a score, allowing for monitoring over time and anticipating maintenance. This system is crucial for infrastructure managers to make informed decisions about bridge safety and durability.

This study classifies the degree of degradation of steel bridges using the IQOA scoring system. Table 3 illustrates the concept of assessing and categorizing structures using the comprehensive performance indicator (CPI). A Class 1 design has a fair apparent condition and a CPI score between 0 and 2. Class 3U, on the other hand, denotes a very critical condition with severe structural failure (CPI score of 8–10).

Table 3 – IQOA classification to evaluate the degradation of steel bridges

Class	CPI	Apparent Condition
1	[0,2]	Good overall state
2	[2,4]	Equipment failures or minor structure damage. Non urgent maintenance needed
2E	[4,6]	Equipment failures or minor structure damage. Urgent maintenance needed
3	[6,8]	Structure deterioration. Non urgent maintenance needed
3U	[8,10]	Serious structure deterioration. Urgent maintenance needed

Results analysis

In order to optimize the procedure, the algorithm calculation process was carried out using Excel spreadsheet software, as shown in Figure 5. Based on the criteria evaluation scale in terms of TFNs (Figure 8), a detailed examination of the comparisons conducted between the various parameters is presented in Table 4. The Consistency Ratios (CR) demonstrated strong coherence, with every CR falling below the usual threshold, following a comprehensive analysis of the judgement matrices to confirm their consistency.

Table 4 – Matrices used for pairwise comparisons and the consistency tests results

C1	C2	C3	C4	C5	Consistency test
$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{6}^{-1}$	$\tilde{2}$	$\tilde{2}$	$\lambda_{\max}=5.022$, CI=0.005, RI=1.120, CR=0.48%< 10%
$\tilde{2}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{4}$	$\tilde{4}$	
$\tilde{6}$	$\tilde{3}$	$\tilde{1}$	$\tilde{9}$	$\tilde{9}$	
$\tilde{2}^{-1}$	$\tilde{4}^{-1}$	$\tilde{9}^{-1}$	$\tilde{1}$	$\tilde{1}$	
$\tilde{2}^{-1}$	$\tilde{4}^{-1}$	$\tilde{9}^{-1}$	$\tilde{1}$	$\tilde{1}$	
C1.1	C1.2	C1.3	C1.4		$\lambda_{\max}=4.001$, CI=0.005, RI=0.900, CR=0.05%< 10%
$\tilde{1}$	$\tilde{2}$	$\tilde{1}$	$\tilde{2}$		
$\tilde{2}^{-1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{1}$		
$\tilde{1}$	$\tilde{2}$	$\tilde{1}$	$\tilde{2}$		
$\tilde{2}^{-1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{1}$		



C1	C2	C3	C4	C5	Consistency test		
C2.1	C2.2	C2.3	C2.4				
$\tilde{1}$	$\tilde{2}$	$\tilde{1}$	$\tilde{4}$		$\lambda_{\max}=4.050$, $CI=0.017$, $RI=0.900$, $CR=1.86\%<10\%$		
$\tilde{2}^{-1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{3}$				
$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{3}$				
$\tilde{4}^{-1}$	$\tilde{3}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}$				
C3.1	C3.2						
$\tilde{1}$	$\tilde{1}$				CR not verified for comparison between two criteria		
$\tilde{1}$	$\tilde{1}$						
C3.1.1	C3.1.2	C3.1.3	C3.1.4	C3.1.5	C3.1.6	C3.1.7	C3.1.8
$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{3}^{-1}$	$\tilde{2}$	$\tilde{2}$
$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{3}^{-1}$	$\tilde{2}$	$\tilde{2}$
$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{3}^{-1}$	$\tilde{2}$	$\tilde{2}$
$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{3}^{-1}$	$\tilde{2}$	$\tilde{2}$
$\tilde{2}$	$\tilde{2}$	$\tilde{2}$	$\tilde{2}$	$\tilde{1}$	$\tilde{1}$	$\tilde{4}$	$\tilde{4}$
$\tilde{3}$	$\tilde{3}$	$\tilde{3}$	$\tilde{3}$	$\tilde{1}$	$\tilde{1}$	$\tilde{6}$	$\tilde{6}$
$\tilde{2}^{-1}$	$\tilde{2}^{-1}$	$\tilde{2}^{-1}$	$\tilde{2}^{-1}$	$\tilde{4}^{-1}$	$\tilde{6}^{-1}$	$\tilde{1}$	$\tilde{1}$
$\tilde{2}^{-1}$	$\tilde{2}^{-1}$	$\tilde{2}^{-1}$	$\tilde{2}^{-1}$	$\tilde{4}^{-1}$	$\tilde{6}^{-1}$	$\tilde{1}$	$\tilde{1}$
C3.2.1	C3.2.2	C3.2.3	C3.2.4	C3.2.5			
$\tilde{1}$	$\tilde{3}$	$\tilde{3}$	$\tilde{2}$	$\tilde{4}$			
$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{2}$			
$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{2}$			
$\tilde{2}^{-1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{2}$			
$\tilde{4}^{-1}$	$\tilde{2}^{-1}$	$\tilde{2}^{-1}$	$\tilde{2}^{-1}$	$\tilde{1}$			
C4.1	C4.2	C4.3	C4.4	C4.5	C4.6		
$\tilde{1}$	$\tilde{2}$	$\tilde{1}$	$\tilde{2}$	$\tilde{2}^{-1}$	$\tilde{1}$	$\lambda_{\max}=6.098$, $CI=0.020$, $RI=1.24$, $CR=1.58\%<10\%$	
$\tilde{2}^{-1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{1}$		
$\tilde{1}$	$\tilde{2}$	$\tilde{1}$	$\tilde{2}$	$\tilde{1}$	$\tilde{1}$		
$\tilde{2}^{-1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{1}$		
$\tilde{2}$	$\tilde{3}$	$\tilde{1}$	$\tilde{3}$	$\tilde{1}$	$\tilde{2}$		
$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{1}$		

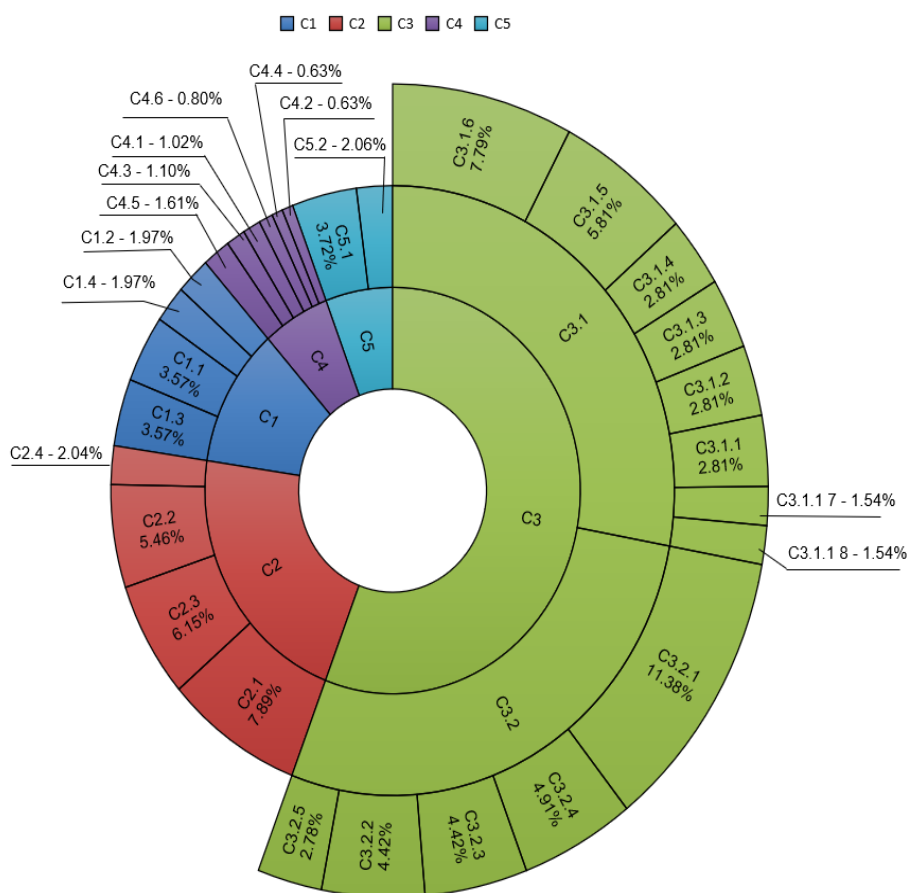
C1	C2	C3	C4	C5	Consistency test
C5.1	C5.2				
$\tilde{1}$	$\tilde{2}$				CR not verified for comparison between two criteria
$\tilde{2}^{-1}$	$\tilde{1}$				

Table 5 presents a concise overview of the weights allocated to the several evaluation criteria, both locally and globally, following the verification of their coherence. The results emphasize the great significance placed on situations of structural disorder, which account for 55.80% of the total weight at the first level of the hierarchy. The environmental conditions account for 21.55% of the degradation of metal bridges, highlighting the substantial impact of the environment on their deterioration. Conversely, the structure's historical condition, equipment deterioration conditions, and monitoring conditions were given lower weights of 11.09% and 5.78% respectively, indicating that these elements have a less significant influence on the overall condition of the structures. Figure 10 shows a hierarchical sunburst diagram, a useful data visualization tool for organizing information. Each circular ring represents a level in a hierarchy, with each segment representing a category. This intuitive representation helps understand interconnections and patterns. However, the diagram reveals significant discrepancies in the overall significance of sub-factors, highlighting their impact on steel bridge deterioration.

Table 5 – Weights assigned to factors and sub-factors at both local and global levels

Level 1		Level 2		Level 3		Global weights
Factors	Local weights w_i	Sub-Factors	Local weights w_i	Sub-Factors	Local weights w_i	W_i
C1	0.1109	C1.1	0.3219	-	-	0.0357
		C1.2	0.1781	-	-	0.0197
		C1.3	0.3219	-	-	0.0357
		C1.4	0.1781	-	-	0.0197
		C2.1	0.3663	-	-	0.0789
C2	0.2155	C2.2	0.2534	-	-	0.0546
		C2.3	0.2854	-	-	0.0615
		C2.4	0.0949	-	-	0.0204
				C3.1.1	0.1006	0.0281
C3	0.558	C3.1	0.500	C3.1.2	0.1006	0.0281
				C3.1.3	0.1006	0.0281
				C3.1.4	0.1006	0.0281
				C3.1.5	0.2081	0.0581
				C3.1.6	0.2793	0.0779
				C3.1.7	0.0551	0.0154
				C3.1.8	0.0551	0.0154

Factors	Level 1	Level 2		Level 3		Global weights
	Local weights w_i	Sub-Factors	Local weights w_i	Sub-Factors	Local weights w_i	W_i
C4	0.0578	C3.2	0.500	C3.2.1	0.4078	0.1138
				C3.2.2	0.1584	0.0442
				C3.2.3	0.1584	0.0442
				C3.2.4	0.1759	0.0491
				C3.2.5	0.0995	0.0278
		C4.1	0.1763	-	-	0.0102
		C4.2	0.1087	-	-	0.0063
C5	0.0578	C4.3	0.1895	-	-	0.0110
		C4.4	0.1087	-	-	0.0063
		C4.5	0.2791	-	-	0.0161
		C4.6	0.1377	-	-	0.0080
		C5.1	0.6439	-	-	0.0372
		C5.2	0.3561	-	-	0.0206



Ultimate goal: categorization of the steel bridge at Oued Taria

We invited an expert to the site to conduct a precise assessment of the Oued Taria bridge's condition. The objective was to allocate a relative condition rating (ER) to each of the previously stated criteria. The rating, which spans from 0 to 10, indicates the influence of each criterion on the overall deterioration of the metal structure of the bridge. A score of 0 signifies a minimal effect, while a score of 10 corresponds to a significant effect. Simply put, a higher score indicates that the criterion contributed more to the deterioration of the bridge. Table 6 succinctly presents the findings of this assessment, which adheres to the comprehensive methodology outlined in the preceding sections.

Table 6 – Assessment of sub-criteria and categorization of the analyzed steel bridge

N°	Factors	ER	W _i (%)	ER × W _i
1	C1.1	3.70	0.0357	0.1321
2	C1.2	3.00	0.0197	0.0592
3	C1.3	5.00	0.0357	0.1784
4	C1.4	1.00	0.0197	0.0197
5	C2.1	5.00	0.0789	0.3946
6	C2.2	5.00	0.0546	0.2731
7	C2.3	9.00	0.0615	0.5535
8	C2.4	3.00	0.0204	0.0613
9	C3.1.1	3.00	0.0281	0.0842
10	C3.1.2	1.00	0.0281	0.0281
11	C3.1.3	1.00	0.0281	0.0281
12	C3.1.4	3.00	0.0281	0.0842
13	C3.1.5	3.00	0.0581	0.1742
14	C3.1.6	1.00	0.0779	0.0779
15	C3.1.7	3.00	0.0154	0.0461
16	C3.1.8	7.00	0.0154	0.1075
17	C3.2.1	7.00	0.1138	0.7963
18	C3.2.2	7.00	0.0442	0.3094
19	C3.2.3	7.00	0.0442	0.3094
20	C3.2.4	7.00	0.0491	0.3435
21	C3.2.5	5.00	0.0278	0.1388
22	C4.1	7.00	0.0102	0.0714

N°	Factors	ER	W _i (%)	ER × W _i
23	C4.2	5.00	0.0063	0.0314
24	C4.3	7.00	0.0110	0.0767
25	C4.4	9.00	0.0063	0.0566
26	C4.5	9.00	0.0161	0.1453
27	C4.6	9.00	0.0080	0.0717
28	C5.1	9.00	0.0372	0.3352
29	C5.2	9.00	0.0206	0.1854
CPI = $\sum_{i=1}^{29} W_i \times ASC_i = 5.173$, class: 2E, Degradation of equipment or minor structural damage. Urgent maintenance is required.				

On a scale from 0 to 10, the comprehensive performance indicator (CPI) yielded a score of 5.173 for the overall evaluation of the steel bridge, as shown in Table 6. The bridge is categorized as Class 2E in Table 3. Equipment deterioration or minor structural damage necessitating immediate repair is indicated by this categorization.

Conclusion

This study used a Fuzzy Analytical Hierarchy Process (FAHP) approach to thoroughly evaluate and classify the condition of steel truss bridges. The 36 carefully chosen criteria and sub-criteria that made up the hierarchical structure made it possible to find the factors that had the most significant effect on the final assessment of the bridge's condition. This hierarchical structure categorizes the different aspects, such as structural disorders, environmental conditions, the bridge's historical background, equipment degradation, and professional intervention, according to their respective levels of importance. The application of this methodology to the Oued Taria bridge revealed minor structural damage and equipment degradation, necessitating increased monitoring and preventive maintenance. Although the FAHP approach allows for uncertainty management and subjectivity reduction through fuzzy logic, the role of experts remains critical in score assignment. The proposed method aims to minimize this issue by rationalizing the process and facilitating rapid and efficient implementation. Furthermore, its user-friendly formulation and adaptability to various contexts make it a practical tool for evaluating the condition of steel bridges.

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Praćenje degradacije čeličnih mostova primenom višekriterijumskih pristupa

Mostefa Lallam^a, **autor za prepisku**, Abdelkader Djebli^b

^a Mustapha Stambouli University, Department of Civil Engineering, Mascara, People's Democratic Republic of Algeria +
Laboratory Mechanics of Structures, University of Tahri Mohamed, Bechar, People's Democratic Republic of Algeria

^b Mustapha Stambouli University, Department of Mechanical Engineering, Mascara, People's Democratic Republic of Algeria +
Laboratory of Mechanics of Materials, Energy and Environment (L2M2E), Mascara, People's Democratic Republic of Algeria

OBLAST: građevinarstvo

KATEGORIJA (TIP) ČLANKA: originalni naučni rad

Sažetak:

Uvod/cilj: Cilj rada je formulacija metode zasnovane na fazi analitičkom hijerarhijskom procesu (eng. FAHP) koja može pomoći stručnjacima u ispitivanju čeličnih mostova. Pristupi zasnovani na fazi logici su poželjni zbog svoje sposobnosti da obrađuju neizvesne informacije na način koji odražava procese ljudskog rasuđivanja, što ih čini posebno pogodnim u proceni oštećenja konstrukcija.

Metode: Postupak je organizovan u hijerarhijskom okviru koji se sastoji od 35 kriterijuma i podkriterijuma. Ova struktura je osmišljena tako da

pomogne zainteresovanim stranama koje učestvuju u ispitivanju pri donošenju odluka. Težinski koeficijenti W_i ovih kriterijuma određuju se primenom metode fazi analitičkog hijerarhijskog procesa i dodatnih ekspertskih procena kako bi se izračunao sveobuhvatni pokazatelj performansi (eng. CPI) koji predstavlja stepen oštećenja ispitivanog mosta. Konstrukcija se klasifikuje na osnovu ukupne vrednosti CPI korišćenjem notacije IQOA.

Rezultati: Radi rigorozne procene praktične primenljivosti i tačnosti razvijene metodologije FAHP, ova studija slučaja je urađena na stvarnoj konstrukciji. Metodologija je primenjena za procenu stanja čeličnog mosta koji se nalazi u Ued Tariji, u regionu Maskara. Primena ovog sveobuhvatnog pristupa dala je rezultate koji su pokazali izuzetnu usklađenost i snažnu povezanost sa prethodnim nezavisno sprovedenim ekspertskim procenama iste konstrukcije.

Zaključak: Uspešna primena i potvrđeni rezultati nedvosmisleno potvrđuju naučnu efikasnost i praktičnu korisnost ovog alata zasnovanog na metodi FAHP. On predstavlja robustan i pouzdan sistem za podršku procesu odlučivanja i značajno unapređuje sposobnosti stručnjaka za preciznu procenu složenih i često subjektivnih aspekata oštećenja čeličnih mostova. Ova metodologija ne samo da pojednostavljuje proces ispitivanja, već doprinosi i objektivnijim i doslednijim procenama, što u krajnjem rezultatu dovodi do boljeg planiranja održavanja i veće bezbednosti kritične mostovske infrastrukture.

Ključne reči: čelični mostovi, fazi analitički hijerarhijski proces (FHAP), sveobuhvatni pokazatelj performansi (CPI).

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