DESIGN ALIGN: INTEGRATING THE PAIRWISE COMPARISON METHOD FOR DECISION-MAKING IN THE PRELIMINARY DESIGN OF BRIDGES

R KAKA* **and S RAVJEE****

Zutari (Pty) Ltd; Riverwalk Office Park, 41 Matroosberg Road, Ashlea Gardens 0081;
Tel: 012 427 2000; Email: *Raheemah.Kaka@zutari.com; **Sachin.Ravjee@zutari.com

ABSTRACT

Effective communication and decision-making between clients and design teams are essential for developing optimal transportation solutions, particularly in bridge design. This paper explores the use of the pairwise comparison method, for selecting the preferred design solution by evaluating and prioritising various constraints. Possible key constraints could include construction cost and time, maintenance, safety, aesthetics, environmental and social considerations, driver comfort, as well as the potential for future expansion.

The pairwise comparison method involves comparing the relative importance of each constraint against the others, using a weighted scoring system. Quantifiable constraints, such as construction cost and time, are assigned specific values, while non-quantifiable factors, such as safety and aesthetics, are evaluated with a preference rating. This process ensures a clear ranking of priorities, allowing both clients and design teams to align on key project goals and facilitates effective communication.

Additionally, the method's flexibility allows for quick adjustments in response to stakeholder feedback, enabling the design team to re-evaluate the constraints and propose new design solutions as needed. Ultimately, this approach leads to a more collaborative and informed decision-making process, where clients gain a balanced understanding of the requirements and constraints, resulting in the preferred bridge design solution that meets both technical and stakeholder needs.

Keywords: Pairwise comparison, Multi-Criteria Decision-Making (MCDM), Bridge preliminary design, Stakeholder engagement.

1. INTRODUCTION

This paper introduces a potential approach to optimise decision-making in the preliminary bridge design phase, a critical but often underdefined stage (Kou et al., 2016). This phase, essential for defining the bridge's purpose and initial form, typically involves consultations with clients and stakeholders. However, the process can become inefficient and repetitive due to ineffective communication of their needs, with experienced engineers often defaulting to familiar design solutions. This tendency limits innovation and adaptability, prolonging the decision-making process and causing delays (Xegwana et al, 2024).

Traditional design approaches, often fail to adequately integrate stakeholder priorities and often overlook important trade-offs. There is a pressing need to develop a quantifiable, stakeholder-driven decision-making framework specific to bridge design. To address this gap, this paper proposes the application of the pairwise comparison method as a structured approach to evaluate and prioritise constraints, to help select the most suitable design solution (Bucholc et al., 2018).

By focusing on the challenges of bridge design and the opportunities for improvement, this paper demonstrates how the pairwise comparison method can balance technical, financial, environmental, and social considerations. It highlights the importance of clear, uncomplicated communication during the preliminary phase, which significantly impacts the success of subsequent project stages and saves time overall (Farkas, 2011).

1.1 Background

Technical aspects form the backbone of bridge design, encompassing specifications that ensure safety, stability, and functionality. These requirements are governed by engineering standards, regulations, and best practices, leaving little room for flexibility. Clear communication of these constraints to and from stakeholders is critical to maintaining alignment and avoiding misunderstandings. Technical considerations serve as the foundation upon which other design factors are built (Farkas, 2011).

Stakeholder input, particularly from the community directly impacted by the bridge, is crucial. Engaging with the local community ensures that the design reflects their needs and concerns, creating acceptance and support for the project. Neglecting this aspect can lead to resistance or delays, whereas effective engagement early in the project, can smooth the progression of the project and through the design bring to life the character of the host community. In addition to incorporating stakeholder feedback, balancing financial constraints with technical requirements is a significant challenge. Achieving a cost-effective design without compromising on quality requires careful planning. Finding a sweet spot between cost, quality, and expectations is important (Widianingrum, 2018). Refer to Figure 1 below.

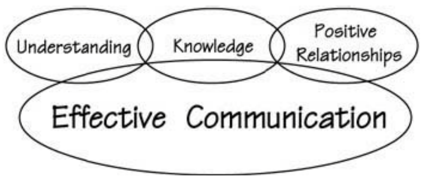

Figure 1: Mechanics of basic communication (Rajkumar, 2010)

Environmental considerations are another key element of bridge design. Engineers have an ethical obligation to consider the environmental impact of their structures. Bridges must coexist harmoniously with their natural surroundings, as they become part of the ecosystems around them (Penadés-Plà et al., 2016). Collaborative efforts with environmental experts and stakeholders can help mitigate potential ecological impacts. Furthermore, bridges are designed to stand the test of time, addressing present-day requirements while anticipating future expansions. A sustainable and adaptable design ensures that the bridge remains relevant and functional for decades to come, creating a legacy (Venkateswaran, 2021).

A common factor across all these considerations is communication. This essential aspect must be embraced and used as a tool to enhance project outcomes, rather than becoming a hindrance (Rajkumar, 2010). Communication, whether conveying technical constraints or addressing stakeholder concerns, serves as a project's immunity, shielding it from potential conflicts and obstacles, while supporting a smooth project execution (Widianingrum, 2018).

1.1.1 Current Decision-Making Methods in Preliminary Bridge Design

Traditional methods in preliminary bridge design rely heavily on phased engineering approaches, such as the Type, Size, and Location (TS&L) phase and the preliminary plan phase. These phases involve developing multiple design alternatives, evaluating superstructure and substructure options, and using engineering judgment alongside “rules of thumb”. Progress is typically tracked through milestones to ensure systematic advancement. Decisions in these phases are guided by limited geotechnical and hydraulic data, conservative cost estimates, and preliminary stress design to provide clients with early project feasibility and layout options (WSDOT, 2022). Stakeholders are frequently excluded from the initial planning stages under the assumption that they may not fully understand technical aspects, leading to inefficiencies and the need to revisit and revise plans in the later stages of the project (Smith, 2000).

The Bridge Engineering Handbook by Troitsky (2000) further highlights the critical role of TS&L studies in establishing foundational parameters through comparative analysis of alternative designs. Factors such as site constraints, span arrangements, and material suitability are evaluated to narrow down viable options.

Current methods face challenges due to limited data availability in early phases, which leads to reliance on conservative estimates and oversimplified “rules of thumb”. The phased milestone approach can constrain iterative design refinement, while minimal stakeholder engagement in preliminary phases risks misalignment with broader project goals (WSDOT, 2022). Additionally, overreliance on senior engineers' experience may introduce bias, and risk management for complex conditions often delays decision-making. These limitations highlight the need for more dynamic, data-driven, and inclusive decision-making frameworks in bridge design (Xegwana et al., 2024).

According to Farkas (2011), structured decision-making frameworks are important in selecting bridge designs as they help balance various competing factors. The study introduces methods like the Analytic Hierarchy Process (AHP) and Kane Simulation Technique (KSIM), which emphasise the critical role of stakeholder engagement in identifying and prioritising evaluation criteria. Through a case study in Pittsburgh, the research demonstrated how initial evaluations using AHP favoured a truss bridge, but further engagement led to the selection of a tied-arch bridge. This shift highlights the dynamic and subjective nature of decision-making in bridge design (Kou et al., 2016).

Despite the demonstrated effectiveness of these methods, there is little evidence of their application in South Africa, especially during the preliminary design phase. This omission highlights a significant gap in integrating multi-criteria decision-making tools into infrastructure development within the country. South African bridge projects, often constrained by budget, environmental concerns, and diverse stakeholder expectations, could benefit greatly from structured approaches. (Xegwana et al., 2024).

1.1.2 Communication Issues With Stakeholders

In South Africa, communication challenges in the construction industry are prevalent, particularly between demand and supply-side stakeholders. A study by Ndebele et al. (2017) highlights that communication issues often arise from a lack of empathy and understanding among stakeholders, leading to misunderstandings and project delays. Furthermore, a study by Mtsweni et al. (2023) on stakeholder engagement in South African construction projects reveals that insufficient engagement can lead to community frustration and protests, with factors such as inadequate communication strategies and lack of transparency affecting effective involvement. The African Development Bank Group (2021) highlights the importance of clear communication strategies, emphasising that effectively addressing stakeholder concerns is essential for the success of infrastructure projects. This is particularly true for complex developments such as bridge construction. Berenger and Agumba (2016) identify common communication barriers in South Africa’s construction industry, including cultural and language differences, inadequate communication systems, and hierarchical organisational structures that limit free communication between different parties. These barriers can lead to misunderstandings, delays, and cost escalations. The authors recommend improving communication through better training, the use of modern technological tools, and fostering a culture of open communication to enhance project outcomes and ensure successful collaboration between designers, contractors and public stakeholders.

These studies collectively demonstrate that effective communication in the preliminary design phase is vital for successful bridge projects, helping to mitigate misunderstandings and enhance overall project outcomes.

1.1.3 The Pairwise Comparison Method in Multi-Criteria Decision-Making (MCDM)

The theoretical foundation of pairwise comparison can be traced to early psychological studies on judgment and decision-making. In 1927, Thurstone introduced the Law of Comparative Judgment, which provided a scientific framework for using pairwise comparisons to measure differences between stimuli (Thurstone, 1927). This work was essential in understanding how individuals perceive relative differences, laying the groundwork for modern decision-making models.

Building upon Thurstone's principles, the pairwise comparison method was further developed and formalised in various MCDM models. For instance, methods such as the Analytical Hierarchy Process (AHP) use pairwise comparison matrices to evaluate multiple alternatives, enabling structured decision-making in complex scenarios (Saaty, 1980). This method allows decision-makers to break down problems into manageable parts and systematically compare each option.

1.1.4 Applications of Pairwise Comparison in Transport Infrastructure

In the public transportation sector, particularly bus services, the pairwise comparison method has been applied to assess service quality. A study (Moslem et al., 2019) introduced a questionnaire survey using pairwise comparisons to collect data for estimating the quality of bus transport services. This approach allowed for an evaluation of various service attributes, aiding in identifying areas for improvement and enhancing overall service delivery.

Furthermore, pairwise comparisons are widely used in the context of selecting priority public transportation projects. A study by (Akhrouf et al., 2023) employed pairwise comparison to determine the relative weights of various criteria, assisting in the evaluation of alternatives and enabling decision-makers to prioritise projects that align with strategic goals and resource availability.

In road and bridge construction, the pairwise comparison method plays a significant role in tender evaluations by comparing various criteria, such as cost, quality, and time. A study by (Bucholc et al., 2018) introduced the Concluder tool, which uses pairwise comparisons to assist in tender evaluations, ensuring a systematic and transparent selection process.

While the method has proven successful in post-service evaluations and decision-making processes across various sectors, its application has been largely limited to these stages. However, the methodology's effectiveness in these areas emphasises its potential for broader implementation, particularly during the preliminary design phase of infrastructure projects like bridge design.

2. METHODOLOGY

2.1 Pairwise Comparison Overview

The key steps in the pairwise comparison process involve the following:

- Defining constraints and criteria: Identify the key factors influencing the decision. These criteria should align with the problem's objectives while keeping the number manageable to avoid overcomplicating the analysis.
- Creating the matrix: Construct a comparison matrix to evaluate the relative importance of each criterion. The matrix entries compare one criterion against another, and diagonal elements represent equal importance. Reciprocal values ensure logical consistency in comparisons.
- Assigning weights: Assign numerical weights to reflect the relative importance of each criterion. The scale introduced by Saaty (1980) in the Analytic Hierarchy Process is widely used, and to simplify the process, weights can also be assigned letters representing these numerical values. A possible weighting scale is provided in Table 1 below.

Table 1: Weighting scale example (Saaty, 1980)

Letter	Weight	Importance Level
A	1	Equal importance
B	3	Moderate importance
C	5	Strong importance
D	7	Very strong importance
E	9	Extreme importance

- Calculating results: Different methods can be used to determine weights and rank alternatives effectively. A common method is the normalisation method, which divides each element in a column by the sum of that column. The averages of each row are then the weightings per criterion.
- Consistency checks: To ensure reliable results, the Consistency Ratio (CR) evaluates whether judgments are logically consistent. A CR below 0.1 indicates acceptable consistency; otherwise, the comparisons require review (Saaty, 1980).

2.2 Adapting Pairwise Comparison for Bridge Design

As previously mentioned, the pairwise comparison method can be tailored to address the unique challenges of bridge design, where multiple constraints and stakeholder priorities must be balanced. The following steps outline the process:

2.2.1 Define Constraints and Criteria

The following are potential constraints that could be used for bridge preliminary design:

- Construction cost: Budget and lifecycle costs.
- Safety: Compliance with structural integrity and safety standards for users and construction workers during construction and operation of the structure.
- Maintenance & durability: Longevity and resistance to wear, maintenance costs, and frequency.
- Construction time: Project deadlines and disruptions.

- Environmental impact: Minimising ecological disruption and using sustainable construction materials and techniques.
- Social considerations: Impact on communities, accessibility, and benefits.
- Aesthetics: Visual appeal and integration into surroundings.
- Constructability: Feasibility of the design, considering complexity, available technology, and local resources.
- Future expansion: Adaptability for future growth.

2.2.2 Engage Stakeholders

Collaborate with engineers, environmentalists, local authorities, and communities to ensure diverse perspectives are considered. Stakeholders should be given access to discuss weightings and changes in the pairwise comparison matrix to ensure inclusivity in decision-making.

2.2.3 Matrix Development and Analysis

The matrix development and analysis phase is where the pairwise comparison methodology comes to life. This involves constructing the matrix, assigning weights, performing calculations, and ensuring consistency. The following are the basic steps to develop the matrix:

- Construct the comparison matrix: Compare each constraint against others for each criterion using a predefined scale.
- Populate the matrix: Insert corresponding values based off stakeholder discussions and judgment. Ensure reciprocal values are maintained.
- Normalise the matrix: Normalise the matrix by dividing each element by the sum of its column. Calculate the average of each row to derive the weights.
- Validate consistency: Compute the CR. Ensure that the matrix meets the logical threshold (CR < 0.10).

2.2.4 Analysis and Interpretation

- Prioritise alternatives: Rank design options based on their weights.
- Assess trade-offs: Discuss compromises with relevant stakeholders. A higher-ranked design may excel in certain criteria but may require sacrifices in others.
- Visualise results: Use bar charts or heatmaps to present findings for clarity and further stakeholder engagements.

3. APPLICATION

To demonstrate the versatility of the pairwise comparison method in bridge design, we examine three examples where the same method yields different results based on varying stakeholder priorities, client requirements, and local contexts. Each example evaluates three distinct design options, emphasising how stakeholder preferences shape decision-making as follows:

- Design Option 1: A basic reinforced / prestressed concrete bridge focusing on functionality and cost-effectiveness.
- Design Option 2: A signature cable-stayed / suspension bridge design, emphasising aesthetics and iconic value.
- Design Option 3: A steel truss bridge offering a balance of structural efficiency and reduced construction time.

Table 2 below presents a comparative ratings evaluation of the three design options, highlighting their respective strengths and weaknesses as part of this example. Each constraint is assigned ratings to evaluate their relative suitability in addressing specific project requirements.

Table 2: Design option evaluation example

Constraint	Design Option 1	Design Option 2	Design Option 3
Construction Cost	Lowest Cost	Highest Cost	Moderate Cost
Maintenance & Durability	Least Maintenance	Moderate Maintenance	Most Maintenance
Safety Requirements	High	Moderate	Moderate
Construction Time	Moderate	Low	High
Environmental Considerations	High	Moderate	Moderate
Social Considerations	Low	High	Moderate
Aesthetics	Low	High	Moderate
Constructability	High	Low	High
Future Expansion	High Possibility	Moderate Possibility	High Possibility

The next step is to obtain the weightings of the constraints by using the scoring system proposed in Table 3 below. Here, each constraint is evaluated against every other constraint to get the overall weightings for the design.

Table 3: Design option evaluation example

Symbol	Definition
A	Strongly More Important
B	Slightly More Important
C	Equally Important
D	Slightly Less Important
E	Strongly Less Important

Three different examples are considered, for three hypothetical clients as follows:

3.1 Client 1: Government Client in Africa

In this scenario, the government client operates within a budget-constrained environment, where construction cost is the primary concern. The pairwise comparison method prioritises options based on minimising initial investment while ensuring durability and accessibility for local communities. Stakeholder engagement focuses on cost estimates, material availability, and long-term maintenance feasibility. The constraint evaluation for Client 1 is shown in Table 4.

Table 4: Client 1 constraint evaluation

Constraints	Construction Cost	Maintenance & Durability	Safety Requirements	Construction Time	Environmental Considerations	Social Considerations	Aesthetics	Constructability	Future Expansion	Final Weighting
Construction Cost	X	A	D	B	A	A	A	A	A	29.8
Maintenance & Durability		X	D	D	B	B	B	B	A	11.3
Safety Requirements			X	A	A	A	A	A	A	31.2
Construction Time				X	B	B	B	B	B	9.6
Environmental Considerations					X	C	B	D	D	2.9
Social Considerations						X	B	D	B	4.3
Aesthetics							X	D	B	2.5
Constructability								X	C	5.7
Future Expansion									X	2.8

3.2 Client 2: Government Client in Asia

For this case, the focus shifts to a government client in Asia prioritising construction time due to pressing timelines for infrastructure projects or public events. The pairwise comparison considers factors such as construction methods, material availability and efficient supply chains. This prioritisation affects the selection process, likely favouring designs that can be constructed swiftly while meeting essential safety and design standards. The constraint evaluation for Client 2 is illustrated in Table 5.

Table 5: Client 2 constraint evaluation

Constraints	Construction Cost	Maintenance & Durability	Safety Requirements	Construction Time	Environmental Considerations	Social Considerations	Aesthetics	Constructability	Future Expansion	Final Weighting
Construction Cost	X	A	D	D	B	B	B	B	B	16.2
Maintenance & Durability		X	D	D	C	C	B	D	D	4.2
Safety Requirements			X	C	B	B	B	C	B	13.1
Construction Time				X	A	A	A	A	A	34.1
Environmental Considerations					X	D	D	D	E	1.9
Social Considerations						X	C	D	D	4.2
Aesthetics							X	D	D	3.8
Constructability								X	C	9.5
Future Expansion									X	13.0

3.3 Client 3: Private Client in the Middle East

In the third example, a private client emphasises aesthetics, sustainability and social impact. Here, the bridge is envisioned as a landmark to enhance the area's visual identity and attract tourism or investment. The pairwise comparison weights design elements such as aesthetics, cultural symbolism, and environmental harmony, reflecting the client's aspirations for a signature structure with broad social and economic benefits. The constraint evaluation for Client 3 is presented in Table 6.

Table 6: Client 3 constraint evaluation

Constraints	Construction Cost	Maintenance & Durability	Safety Requirements	Construction Time	Environmental Considerations	Social Considerations	Aesthetics	Constructability	Future Expansion	Final Weighting
Construction Cost	X	B	C	D	B	D	D	B	B	10.0
Maintenance & Durability		X	D	D	D	E	E	D	C	2.1
Safety Requirements			X	D	C	C	C	D	D	5.7
Construction Time				X	B	D	C	B	C	12.4
Environmental Considerations					X	D	E	B	B	8.0
Social Considerations						X	D	B	B	18.2
Aesthetics							X	A	A	31.5
Constructability								X	D	5.6
Future Expansion									X	6.5

The final weightings for the different constraints against the three client examples are given in Figure 2 below. The figure shows how constraints could potentially score differently for clients from varying geographies, sectors or cultures.

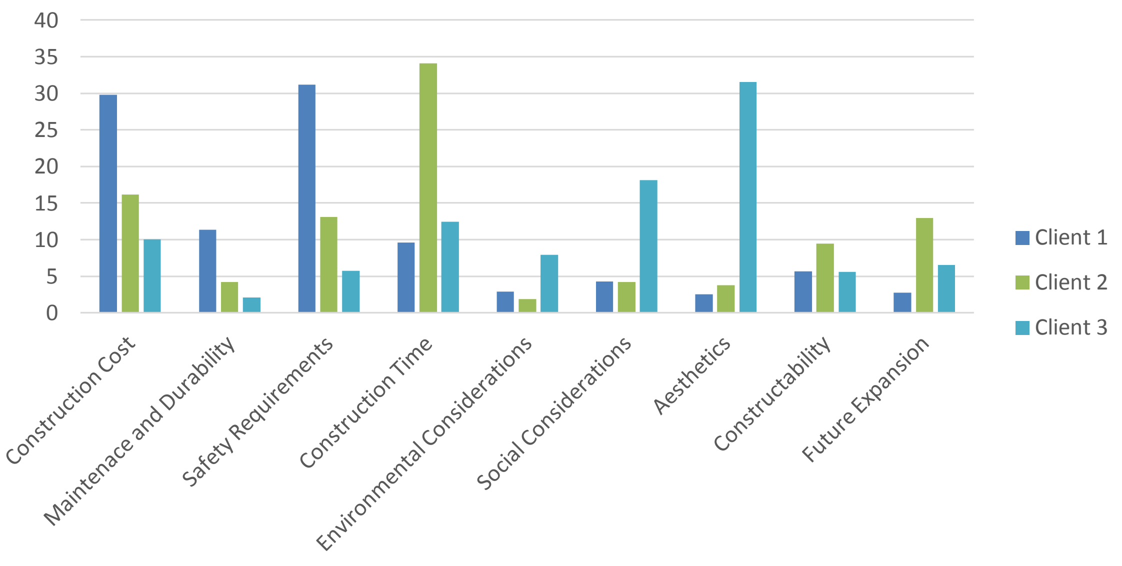

Figure 2: Final weightings for client examples

Once the final weightings (Figure 2) are assessed alongside the design option evaluation scoring (Table 2), preferred design solutions can be determined for the different client examples. As shown in Table 7, different preferred design solutions are found for the three client examples. The results can be summarised as follows:

- Client 1, the government client in Africa, favouring construction cost, safety and maintenance, scored the more conventional reinforced / prestressed bridge design as the preferred design option, which had the lowest envisaged construction cost.

- Client 2, the government client in Asia, with a strong preference on construction time, found the preferred design option to be the steel truss bridge based on easier sourcing of structural steel in Asia, thus reducing construction time.
- Client 3, the Middle Eastern private client, favouring aesthetics, scored the preferred design option as the signature cable-stayed / suspension bridge.

Table 7: Final preferred design solutions for different clients

Design Option	Client 1 African Government		Client 2 Asian Government		Client 3 Middle East Private	
Design Option 1 Conventional Reinforced / Prestressed Bridge	41.1	100.0	37.4	95.7	30.1	0.0
Design Option 2 Signature Cable / Suspension Bridge	26.6	0.0	24.7	0.0	35.1	100.0
Design Option 3 Steel Truss Bridge	32.3	39.4	37.9	100.0	34.8	95.0

4. DISCUSSIONS

4.1 Benefits of the Pairwise Comparison Method

- Adaptability to varying projects: The method is capable of accounting for different project conditions, such as budget constraints, ensuring the preferred design reflects the specific needs of each setting.
- Active stakeholder involvement: By allowing stakeholders to easily merge into the evaluation process, the method enhances collaboration and alignment, with the potential of reducing disputes and delays.
- Conversion of qualitative judgments to quantitative data: It transforms subjective preferences (e.g. aesthetics, safety) into measurable data, promoting more objective comparisons and minimising bias.
- Clear visual outputs: Weighted matrices and rankings provide clear and convenient results, making decisions/changes easier to communicate, justify, and defend to clients or design teams.
- Scalability: The method is suitable for projects of all sizes, as it can evaluate both a few options and complex decision-making scenarios with numerous alternatives and constraints, making it a very attractive approach.
- Consistency checking: Tools like the consistency ratio help identify potential biases or errors in judgment, improving the reliability of the decision-making process.

4.2 Challenges and Limitations of the Pairwise Comparison Method

- Subjective stakeholder preferences: Emotional biases could influence decisions or weightings, causing stakeholders to prioritise certain constraints over others. This could also create inconsistent evaluations due to a lack of clarity on the criteria, especially when comparing multiple design options.
- Time and resource-intensive feedback: Gathering input from a diverse group of stakeholders in large projects can be challenging and slow down the decision-making process.

- Coordinating diverse stakeholder priorities: Ensuring participation from all relevant parties is essential but can lead to conflicting viewpoints that could complicate decision-making.
- Bias from experienced professionals: the experts may unintentionally favour familiar designs, limiting innovation by assigning weightings based on past experiences, emphasising the need for transparency and oversight in the process.
- Ensuring reliability: To improve the method's effectiveness, challenges must be mitigated through independent reviews, which could escalate time required for the preliminary phase.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

- The pairwise comparison method provides a systematic approach for evaluating and prioritising constraints in the preliminary bridge design phase, while considering each constraints importance to the different parties involved in the project.
- By integrating technical requirements, stakeholder input, and environmental considerations, the method ensures a more collaborative, efficient, and adaptable design process that is easily presented and changeable.
- This approach aligns bridge projects with broader project goals and stakeholder expectations, allowing for better outcomes from the get-go.

5.2 Recommendations

- Explore automation through software tools for enhanced accuracy and usability.
- Calibration exercises should be conducted on the constraints and weightings to ensure consistency of assessments.
- The continuous development of AI to improve decision-making processes in bridge maintenance.
- Surveys should be conducted to assess the method's effectiveness, such as the time saved in the preliminary phase and the willingness of stakeholders to adopt it.

6. DECLARATION OF AI IN THE WRITING PROCESS

While preparing this work, the author(s) used ChatGPT to rewrite parts of the text. After using this tool//service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication’s content.

7. REFERENCES

African Development Bank Group. 2021. Stakeholder engagement report. *Limpopo Highway Improvement Project*.

Akhrouf, M, Medjamia, H & Bessou, M. 2023. 'An AHP-Based Approach to Selecting a Priority Public Transportation Mode for Investment', *International Journal of the Analytic Hierarchy Process*, 15(3).

Berenger, YR & Agumba, JN. 2016. The Issue of Communication in the Construction Industry: A case of South Africa. In: O.J. Ebohon, D.A. Ayeni, C.O. Egbu, and F.K. Omole, eds. *Proceedings of the Joint International Conference (JIC) on 21st Century Human Habitat: Issues, Sustainability and Development*, 21-24 March 2016, Akure, Nigeria. Akure: [Publisher], pp. 1729-1738.

Bucholc, K, Koczkodaj, WW & Trochymiak, W. 2018. 'Use of Pairwise Comparison Method in Road-and-Bridge Tenders', WUT, The Faculty of Civil Engineering, *Institute of Roads and Bridges, Department of Bridges and Rail Roads, Warsaw, Poland, Laurentian University, Subury, Ontario, Canada.*

Farkas, A. 2011 'Multi-Criteria Comparison of Bridge Designs', *Acta Polytechnica Hungarica*, 8(1):47-56.

Kou, G, Ergu, D, Lin, C & Chen, Y. 2016 'Pairwise Comparison Matrix in Multiple Criteria Decision Making', School of Business Administration, Southwestern University of Finance and Economics, Chengdu, China.

Moslem, S, Ismael, K & Duleba, S. 2019. *Evaluating Public Bus Transport Supply Quality By Using Pairwise Comparison Scale*. In: *Proceedings of the 3rd International Mediterranean Symposium*. Turkey.

Mtsweni, B, Ncube, M & Khumalo, T. 2023. Assessing factors that influence stakeholder engagement in a construction project at a South African municipality. *Journal of Construction Management and Economics*.

Ndebele, N, Kheswa, M & Zondi, M. 2017. The issue of communication in the construction industry: A case of South Africa. *Journal of Construction Engineering and Management*.

Penadés-Plà, V, García-Segura, T, Martí, JV & Yepes, V. 2016. A Review of Multi-Criteria Decision-Making Methods Applied to the Sustainable Bridge Design. *Sustainability*, 8(12):1301.

Rajkumar, S. 2010. Art of communication in project management. Paper presented at PMI® Research Conference: *Defining the Future of Project Management*, Washington, DC. Newtown Square, PA: Project Management Institute.

Saaty, TL. 1980. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill.

Smith, LW. 2000. *Stakeholder analysis: a pivotal practice of successful projects*. Paper presented at Project Management Institute Annual Seminars & Symposium, Houston, TX. Newtown Square, PA: Project Management Institute.

Thurstone, LL. 1927. A law of comparative judgment. *Psychological Review*, 34:273-286.

Troitsky, MS. 2000 *Bridge Engineering Handbook*. Ed. Wai-Fah Chen and Lian Duan, Boca Raton: CRC Press.

Venkateswaran, B. 2021. Sustainable practices in bridge construction. *Journal of Sustainable Construction Materials and Technologies*, 6(1):24-28.

Washington State Department of Transportation. 2022. Bridge design manual (Publication No. M 23-50). Washington State Department of Transportation.

Widianingrum, R. 2020. *Developing Stakeholder Engagement for Infrastructure Projects: Case Study on Indonesia Infrastructure Roundtable/IRR*. *Infrastructure Development Journal*, 1(1):1-14.

Xegwana, MS, Herron, A & Nyika, F. 2024. *Assessing factors that influence stakeholder engagement in a construction projec at a South African municipality*. *European Project Management Journal*, 14(1).