Application of the Fuzzy AHP inSelectionof Most AppropriateConstruction MethodforTuti- Bahri Bridge

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Abstract:

In presence of many kilometers of waterways and valleysin Khartoum State, bridges had become desperately needed for proper communication and development. There were many types of bridges in Sudan made of concrete and/or steel using various types of suspended, steel truss, arch and cable-stayed bridges which were constructed by different methods. The successes in bridge projects will be reached if the project achieved quality, cost saving and completed in optimum time schedule. Therefore, selecting appropriate bridge construction method is essential for the success of bridge construction projects.

The Analytical Hierarchy Process (AHP) method has been widely used for solving multi-criteria decision-making problems. The Authors applied Fuzzy AHP, similar to the process suggested by Nangin 2008, to select the most appropriate construction method to be adopted for the Cable-stayed Tuti-Bahri Bridge Project which the Ministry of Infrastructures and Transportation of Khartoum State intends to construct at Khartoum city-center.The results were successfully applied for selection of the most appropriate bridge superstructure construction method among two methods.The hierarchy of the alternatives issuggested based on opinion of twoSudanese expertsthroughquestionnairesto obtain thebasic criteria. Weights, from group of evaluations,areanalyzed using excel spread sheets developed by the Authors. Applying Nang's approach revealed logical procedure for selection of construction methodthat best suits Tuti-Bahri Bridge.

مُستَخْلَص:

إن وجود عدة كيلومترات من الممرات المائية والأودية في ولاية الخرطوم جعل الحاجة إلى تشييد الجسور كبيرة لتحسين الإتصال والتنمية. هناك عدة جسور تم تشييدها في السودان من الخرسانة و/أو الفولاذ بإستخدام عدة أنظمة من الجسور

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المعلقة والقوسية والجسور الجملونية والمستوية على كوابل وبعدة طرق تشييد. لذلك فإن إختيار أفضل طريقة لتشييد الجسر تعتبر مهمة لنجاح مشاريع تشييد الجسور.

تستخدم طريقة التحليل الترتيبي (AHP)لحل مسائل تعدد القرارات، وفي هذا البحث تم إستخدام نموذج يعتمد على التحليلالترتيبي العشوائي (FAHP)يشبه النموذجالذي إستخدمه نانق. حيث طُبق النموذج للمساعدة في إ ختيار أفضل طريقة لتشييد جسر توتي –بحري الذي تقوم بتشييده وزارة البنى التحتية والمواصلات في وسط الخرطوم .تم بنجاح تحليل ترتيبي للخيارات والمعايير بالإعتماد على آراء خبيَرين محلييَنومختَصين فى مجال تصميم وتشييد الجسور ذلك من خلال إستبيان بغرض الحصول على المعايير الأساسية اللازمة لإختيار أفضل طريقة تشييد من بين طريقتين مقترحتين . و تمحساب قيمالأوزان بإستخدام أوراق إكْسِل التي أنشأها الباحثان لتحليل مجموعاتنتائج التقييم. أفضت الدراسة إلى أن طريقة (FAHP)المستخدمة تمثل وسيلة منطقية لإيجاد أفضل طريقة لتشييد المنشأة العلوية في مشروع جسر توتي– بحري.

1. Introduction

Bridges in Sudan over the past 100 years were constructed by different techniques using launching gantry, built-up sections, barge–mounted crane, balanced cantilever, formworks and incremental launching.Catastrophic bridge failures such as bridge collapses during construction incurred by the use of inappropriate construction methods can cause considerable loss in terms of time, money, damage and rework. Accordingly, Selection of appropriate erection method is necessary for safety, quality, and saving construction cost and time, [1].

For strategic reasons and infrastructure development, Sudan, in the last two decades, conducted outstanding expansion in the road networks in terms of length, widening of carriageways, strengthening of old bridges and construction of many new bridges.

Many construction systems have been applied to the construction of bridges in Sudan such as: launching, balanced cantilever, and direct erection methods involving formwork and cranes mounted on barges.

Tables (1) and (2) summarize the basic data regarding the 14 main recently constructed bridges in Sudan.

Table (1): Construction data of recentlyconstructed bridges in Sudan, [2]:

No.	Bridge Name	Year of Completion	Bridge Superstructure System	Construction Method
1	Salvation Bridge	1999	Main spans: cast-in-place Prestressed Concrete (PsC) box-girders	Balanced cantilever
			Side spans: PsC girders,	Launching by gantry frame
2	Atbara Bridge	2004	Pre-cast : Reinforced Concrete(RC) I-girders	Erected by Crane
3	Almanshia Bridge	2005	Main spans: cast-in-situ PsC box-girder	Balanced cantilever
			Side spans: PsC girders	Launching by gantry frame
4	Merowe Bridge	2007	6 spans, PsC T- girders	Launched by gantry
			3 spans PsC Box- girders cast insitu	Balanced cantilever
5	Shendi Bridge	2008	17 spans, Precast T-girders, and Box-girders.	Lifted by wires from barge.
6	Al MakNimir Bridge	2008	Main spans: Steel box-girders	Incremental launching.
			Middle two spans: Stayed by cables to steel box pylons.	Incremental launching.
7	Tuti-Khartoum Suspen. Bridge	2009	Two towers: cast in-situ RC. Main span cables. Deck of composite sections.	Cables erected by catwalk. Deck by crane and barge
			Side spans: composite I-girders	Erected by crane
8	Aldamer Bridge	2009	40m long PsC T-girders	Moved on rails and launched by gantry
9	Dongola Bridge	2009	40m long PsC T-girders	moved on rails and launched by gantry
10	Al Dabba Bridge	2010	40m long PsC T-girders	moved on rails and launched by gantry
11	Rufaa Bridge	2010	Main spans: cast in-situ concrete box girder,	Balanced cantilever
			Approach spans: cast in place	By formwork
12	Al Halfaya Bridge	2010	Spans: Composite I-girders.	Lifted by crane. Deck cast-in-situ RC.
13	Khr.Samaha	2011	Pre-cast RC I-girders	Erected by crane
14	Aldueim Bridge	2011	Main spans: cast in-situ concrete box girder,	Balanced cantilever
			Approach spans: cast in place	By formwork

Table (2): Construction Method, Cost and Production Rate, [1]:

Bridge No.	Bridge Name	Main Construction Methodfor the Superstructure	Cost/m^2 (US$)	Production Rate (m^2/week)
1	Salvation	Balanced Cantilever	1,857	167.1
2	Atbara	Erected by Crane	1,597	123.2
3	Alamnshia	Balanced Cantilever	1,784	67.8
4	Merowe	Launched by gantry	1,601	63.1
5	Shendi	Lifted by wires from barge	1,803	116.9
6	Al MakNimir	Incremental launching.	1,652	183.1
7	Tuti–Khartoum	Crane and barge	2,661	80.4
8	Aldamer	Launched by gantry	1,569	171.0
9	Dongola	Launched by gantry	1,628	139.0
10	Al Dabba	Launched by gantry	2,399	125.7
11	Rufaa	Balanced Cantilever	3,338	37.9
12	Al Halfaya	Erected by Crane	1,628	286.7
13	Khor Samaha	Erected by Crane	1,588	192.5
14	Aldueim	Balanced Cantilever	3,122	79.4

For the listed 14 bridges it is worthwhile bringing the attention to the following notes:

i. The above bridges cross either a main river or waterway.

ii. Bored pile foundations were used for all bridges.

iii. Pile cap for most bridges was located above water level. However, some pile caps were constructed under water level using sheet-piles and dewatering techniques.

iv. Pier columns and pile caps were constructed using false formwork and cast-in-situ reinforced concrete.

v. The cost of the approach ramps is excluded for all bridges.

vi. The production per week is a "comprehensive measure" calculated as follows:Production rate = (Length of bridge × its width)/construction time in weeks.

vii. Production rate of Bridge No. 4 was slightly affected by accident during construction: flood washed-out the temporary service bridge.

viii. Bridge No. 7 (suspension bridge) is a special bridge type which is meant to be a land-mark at Khartoum city-centre, hence, the cost and duration is seriously affected.

ix. The high cost and low production rate of Bridges No. 11 and 14 is owing to the narrow width of the bridges and to the contractor being working on both bridges simultaneously.

In light of the above and according to the past experience of the Authors, it is noticed that the cost and duration of the listed bridges is mainly affected by the superstructure system and construction method among other causes.

2. Objectives:

This paper attempts to draw the attention of bridge engineers to importance of proper selection of bridges' superstructure construction method in a way to assist in achieving higher performance, on future projects, regarding cost, safety and construction time. Data of recently constructed main bridges in Sudan is to be presented to highlight the effect of superstructure construction method onthe cost and duration of these bridge projects.

The paper also aims at encouraging the clients and contractors,in Sudan,to adopt the use of logical procedures to guide the selection of the most appropriate bridge superstructure construction method taking Tuti–Bahry Bridge Project as case study to illustrate the procedure.

3. Case Study Review

The Roads, Bridges and Drainage Corporation of Khartoum State planned to construct a new bridge connecting Tuti Island to Bahry. The project owner and the contractor attempted to choose the most appropriate bridge construction method between pre-assigned two methods, namely the **Incremental**

Launching Method and **Balanced Cantilever Method**, Figures (1) and (2) show simplified schematic layout for the two methods.

The construction sequence of the two methods is outlined hereunder:

i. **Incremental Launching Method**: with construction sequence as follows:
   1. Construct piers of the towers.
   2. Introduce temporary intermediate piers.
   3. Erect deck segments by incremental launching.
   4. Construct the upper part of the towers.
   5. Erect the cables.
   6. Remove temporary piers

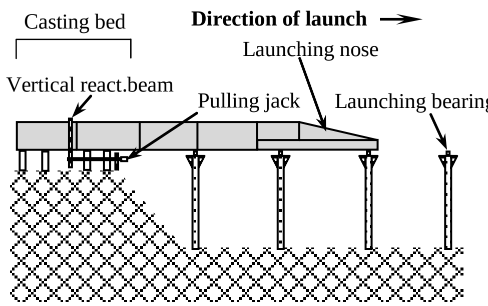


Figure (1): Incremental Launching Method

ii. **Balanced Cantilever Method**: with construction sequence as follows:
   1. Construct the towers.
   2. Introduce cables.
   3. Erect deck segments, two segments: each on one side of the towers.

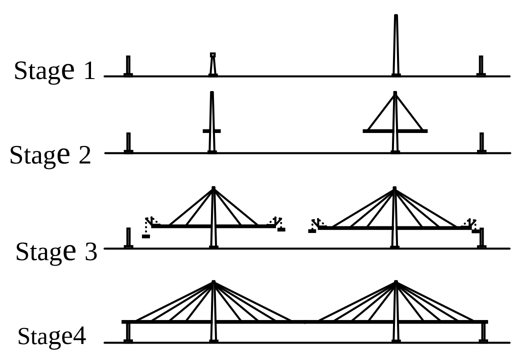


Figure (2): Balanced Cantilever

The Authors applied FAHP similar to Nangmodel,[3], into selection the most appropriate construction method for Tuti – Bahry Bridge as follows:

i. Two expert engineers were asked to identify possible factors that could affect the final decision through several surveys and questionnaires. The criteria used in the hierarchy were obtained and checked through the process using Delphi approach, [4].

ii. The **FIVE** main criteria adopted are similar to Nang main criteria which are: quality, cost, safety, duration, and shape.

iii. The main criteria were further subdivided into sub-criteria: Quality was characterized by durability and suitability; Cost was divided into construction cost and damage cost; Safety was associated with traffic conflict and site condition; Duration was divided into weather condition and constructability that affects productivity. Shape was divided into landscape, geometry, and environmental preservation, see Figure (3).

iv. Once the hierarchy was established, the opinion of two bridge construction experts was obtained via questionnaires. Series of questionnaires were designed and used for direct pair-wise comparison and judgment; sample questions, with respect to the overall goal are shown below:

Q1. How important is quality (C_1) when it is compared to cost (C_2)?
Q2. How important is quality (C_1) when it is compared to safety (C_3)?
Q3. How important is quality (C_1) when it is compared to duration (C_4)?
Q4. How important is quality (C_1) when it is compared to shape (C_5)?
Q5. How important is cost (C_2) when it is compared to safety (C_3)?
Q6. How important is cost (C_2) when it is compared to duration (C_4)?
Q7. How important is cost (C_2) when it is compared to shape (C_5)?
Q8. How important is safety (C_3) when it is compared to duration (C_4)?
Q9. How important is safety (C_3) when it is compared to shape (C_5)?
Q10. How important is duration (C_4) when it is compared to shape (C_5)?

The following Tables 3 to 5present the judgment results of the two experts regarding the importance of one criterion when compared with other criterion.

Table 3: Judgmentresults of the main criterion with respect to the overall goal:

Pair-wise criteria	Opinion of expert #1	Opinion of expert #2
Quality *versus* Cost	VI*	MI
Quality *versus* Safety	EI	VI
Quality *versus* Duration	VI	VI
Quality *versus* Shape	VI	EI
Cost *versus* Safety	LI	MI
Cost *versus* Duration	LI	VI
Cost *versus* Shape	MI	MI
Safety *versus* Duration	VI	MI
Safety *versus* Shape	VI	EI
Duration *versus* Shape	MI	MI

Table 4: Evaluation results of the sub-criteria regarding the main criteria

Pair-wise criteria	Opinion of expert #1	Opinion of expert #2
Durability *versus* Suitability	EI	VI
Damage cost *versus* construction cost	MI	MI
Traffic conflict *versus* site condition	MI	EI
Constructability *versus* weather condition	MI	VI
Landscape *versus* geometry	EI	LI
Landscape *versus* environmental Preservation	LI	EI
geometry *versus* environmental preservation	LI	MI

**Definition of the abbreviations*VI, MI, EI ... *etc.are shown in Table 6.*

Table 5: Judgment results for the two alternatives with respect to the sub-criteria

Sub-criteria	Opinion of expert #1	Opinion of expert #2
Durability [1*]	LI	EI
Durability [2©]	MI	EI
Suitability [1]	LI	VI
Suitability [2]	MI	MI
Damage cost [1]	EI	LI
Damage cost [2]	EI	MI
Construction cost [1]	LI	VI
Construction cost [2]	MI	VI
Traffic conflict [1]	EI	UV
Traffic conflict [2]	EI	UV
Site condition [1]	MI	EI
Site condition [2]	LI	EI
Constructability [1]	MI	MI
Constructability [2]	LI	VI
Weather condition [1]	LI	LI
Weather condition [2]	MI	LI
Landscape [1]	EI	EI
Landscape [2]	EI	EI
Geometry [1]	LI	MI
Geometry [2]	MI	MI
Environmental preservation [1]	LI	LI
Environmental preservation [2]	MI	LI

[*] The superscript 1 denotes the relative importance of Incremental Launching Method when it is compared to Balanced Cantilever Method regarding the sub-criterion.

[©] The superscript 2 denotes the relative importance of Balanced Cantilever Method when it is compared to Incremental Launching Method regarding the sub-criterion.

3.1 The AppliedMethod

The Analytical Hierarchy Process (AHP) applied in this paper is inspired from the one suggested by Nang in reference [3], except that two alternative construction methods are examined here instead of the three alternatives adopted by Nang for the bridge project in Taiwan, [3]. The hierarchy of the decision problem was constructed based on the opinion of two experts who had worked on numerous bridge projects in Sudan for at least ten years. It is worthwhile mentioning that:although Nang adopted 8 experts and Salah and Onsa, [4],analyzed the opinions of 4 experts', the two experts adopted here seem to have had acceptable results).The adopted two alternatives (launching method and balanced cantilever method) are assigned according to the data of recently constructed bridges in Sudan, in particular Khartoum State, see Table 1. The basic hierarchy of the decision problem was constructed based on the experts' suggestions derived by using Delphi approach,[5].

To reflect particular degrees of uncertainty regarding the decision making process, the α-cut concept is applied. In practical applications, α=0, α=0.5, and α=1.0 are used to indicate the decision-making condition that has pessimistic, moderate, and optimistic view, respectively, [6]. Triangular and trapezoidal fuzzy numbers and α-cut concept are applied to deal with the imprecision inherited to the process of subjective judgment, see Figure (4): triangle LNR, trapezoid LMOR.

The steps followed in the analysis and the enhancements made by Nang to Buckley's model, [7] are presented in the following sections.Note that: in such a decision making problem it is intended to identify the most important criterion and their weights that lead to determine the most preferred alternative of bridge construction method

3.2 Construction of the Hierarchy

The typical fuzzy AHP decision problem consists of:

1. Number of alternatives, M_i(i =1, 2 ...m), in this case m = 2.

2. Set of evaluation criterion, C_j(j=1, 2 ...n), in this case n = 5.
3. Linguistic judgment,r_{ij},representing the relative importance of each pair criteria, and
4. Weighting vector, W_i(i = 1,2... n)

The first step of Nang's model is todetermine the entireimportant criterion and their relationship to the decision problem inthe form of a hierarchy as shown in Figure (3),this step is critical because the selectedcriteria can seriously influence the final choice. The hierarchy is structured fromthe top (the overall goal of the problem-selection of the most desirable bridge construction method) through the intermediatelevels (main criteria and sub-criteria) tothe bottom level (the list of alternatives).

The five linguistic variables are described by fuzzy numbers as denoted in Table6. Each negative judgment is characterized by its own (*conjugate*) number to reflect the degree of uncertainty regarding the process, (*note: fuzzy numbers for* VU*versus its negative judgment* VI, *and* LI*versus its negative judgment* MI).

Table 6: Fuzzy importance scale*:

Verbal judgment	Abbreviation	Explanation	Fuzzy number
Very Unimportant	VU	A criterion is strongly inferior to another	(0,0,1,2)
Less Important	LI	A criterion is slightly inferior to another	(1,2.5,4)
Equally Important	EI	Two criteria contribute equally to the object	(3,5,7)
More Important	MI	Judgment slightly favor one criterion over another	(6,7.5,9)
Very Important	VI	Judgment strongly favor one criterion over another	(8,9,10,10)

**Note that (the fuzzy number) "Very Unimportant"and "VeryImportant"are represented by half trapezoidalmembership functions; whereas the remaining levels are characterized by symmetric triangular membership functions.*

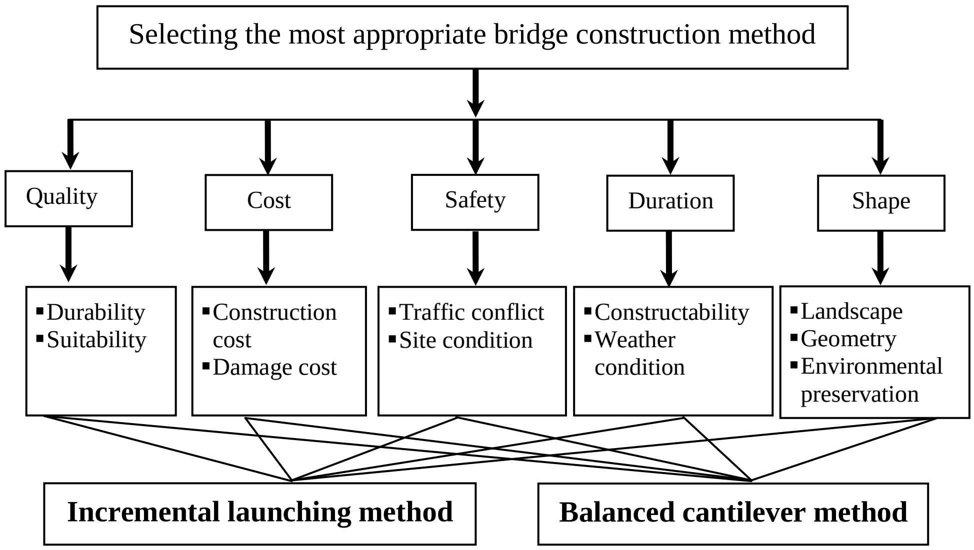


Figure (3): The hierarchy flow chart

The fuzzy comparison matrix based on the judgment **expert #1** is given by:

$$A^{*}=\begin{bmatrix} 1 & (8,9,10,10) & (3,5,7) & (8,9,10,10) & (8,9,10,10) \\ (0,0,1,2) & 1 & (1,2.5,4) & (1,2.5,4) & (6,7.5,9) \\ (3,5,7) & (6,7.5,9) & 1 & (8,9,10,10) & (8,9,10,10) \\ (0,0,1,2) & (6,7.5,9) & (0,0,1,2) & 1 & (6,7.5,9) \\ (0,0,1,2) & (1,2.5,4) & (0,0,1,2) & (1,2.5,4) & 1 \end{bmatrix}$$

Thus, the upper-boundcomparison matrix is given by:

$$A_{U1}=\begin{bmatrix} 1 & 10 & 7 & 10 & 10 \\ 2 & 1 & 4 & 4 & 9 \\ 7 & 9 & 1 & 10 & 10 \\ 2 & 9 & 2 & 1 & 9 \\ 2 & 4 & 2 & 4 & 1 \end{bmatrix}$$

The upper boundsin the above matrix are obtained as the number on the right most for the values between brackets in matrix [*A*]*.

The five membership functions shown in Table (6) can also bemathematically expressed,for other values of α, throughEqs. (1) to (5), [3]:

$$X(\alpha)_{\text{Very Unimportant}} = \begin{cases} X_{\alpha,L} = 0 \\ X_{\alpha,M} = \frac{0.5+(X_{\alpha,L}-1)[(X_{\alpha,L}-1)(0.33+0.17\alpha)+1]}{1+(0.5X_{\alpha,L}-0.5)(1+\alpha)} \\ X_{\alpha,U} = 2-\alpha \end{cases} \quad (1)$$

$$X(\alpha)_{\text{Less Important}} = \begin{cases} X_{\alpha,L} = 1+1.5\alpha \\ X_{\alpha,M} = 2.5 \\ X_{\alpha,R} = 4-1.5\alpha \end{cases} \quad (2)$$

$$X(\alpha)_{\text{Equally Important}} = \begin{cases} X_{\alpha,L} = 3+2\alpha \\ X_{\alpha,M} = 5 \\ X_{\alpha,U} = 7-2\alpha \end{cases} \quad (3)$$

$$X(\alpha)_{\text{More Important}} = \begin{cases} X_{\alpha,L} = 6+1.5\alpha \\ X_{\alpha,M} = 7.5 \\ X_{\alpha,U} = 9-1.5\alpha \end{cases} \quad (4)$$

$$X(\alpha)_{\text{Very Important}} = \begin{cases} X_{\alpha,L} = 8+\alpha \\ X_{\alpha,M} = 8+\frac{1.5+(9-X_{\alpha,L})[(9-X_{\alpha,L})(0.67+0.17\alpha)+0.5]}{1+(4.5-0.5X_{\alpha,L})(1+\alpha)} \\ X_{\alpha,U} = 10 \end{cases} \quad (5)$$

3.3Calculation of element weight:

*The elements of the fuzzy comparison matrix *A* are defined as follows:

$$A = \begin{vmatrix} 1 & (x_{12,L}, x_{12,M}, x_{12,U}) & \dots & (x_{1n,L}, x_{1n,M}, x_{1n,U}) \\ (x_{21,L}, x_{21,M}, x_{21,U}) & 1 & \dots & (x_{2n,L}, x_{2n,M}, x_{2n,U}) \\ \dots & \dots & \dots & \dots \\ (x_{n1,L}, x_{n12,M}, x_{n1,U}) & \dots & \dots & 1 \end{vmatrix}$$

To use the proposed model, the opinion of the two expertsgiven in Table 3, is exemplified.Next, the geometric mean of quality (C_1) with regard to cost (C_2), safety (C_3), duration (C_4), and shape (C_5) can be calculated as follows:

$$W_i = g_i / \sum_{i=1}^{L} g_i \qquad (6)$$

Where, $g_i = \left(\prod_{j=1}^{n} r_{ij}\right)^{\frac{1}{n}}$ …… (7)

$g_i = u_1, u_2 ... u_n$

$u_1 = (1 \times 10 \times 7 \times 10 \times 10)^{1/5} = 5.875$

The calculations for $u_2 \ldots u_5$ are similar to that of u_1.

Similarly, the geometric mean for C_2, C_3, C_4, and C_5 yields 3.103, 5.752, 3.177, and 2.297, respectively. Hence, the relative weight of C_1 can be estimated by using Eq. (6) to get:

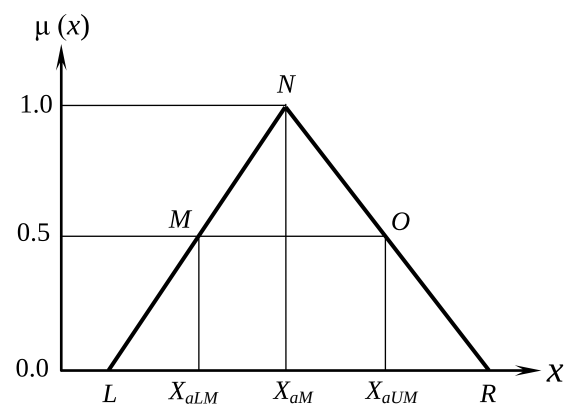
W_1= 5.875/(3.103+5.752+3.177+2.297+5.875)= 0.291

Similarly values of; W_2, W_3, W_4 *and* W_5 can be obtained.

In the above equations: g_i is the geometric mean of criteria i; r_{ij} is the comparison value of criteria i to criteria j; W_i is the i^{th} criterion's weight, where W_i>0 and $\sum^{n}_{i=1} W_i = 1$.

Same procedure is followed to find the weights for C_2, C_3, C_4 and C_5= (0.153, 0.284, 0.157 and 0.113) respectively.

Also, for A_{M1} and A_{L1}, (the middle andlowerbounds comparison matrix) the weights for C_1, C_2, C_3, C_4 and C_5 areobtained.



Figure(4): Triangular fuzzy intervals under α - cut

The weights of C_1 derived from the judgment of expert #1 yield 0.291, 0.323, and **0.336 for α – cut = 0, 0.5** and 1.0 respectively.

Similarly, the weights of C_1 derived from thejudgment of expert #2yield:0.277, 0.308, and 0.342, see Figure (5).

Using Eq. (8), the aggregate of the two expert's evaluations can be obtained as shown in Figure(5). Thus, the representative weight of quality (C_1= 0.3121) can be found using Eq. (9)and Figure(5), seethe calculations below:Where ($X_{12,L}$, $X_{12,M}$, $X_{12,U}$) denotes the lower, middle and upper values of the 1st element compared with the 2nd element, calculated usingEqs. (3) to (7),see results in Figure (4).

Thus, the representative weight of quality (C_1), $Z_{quality}$, can be found by using Eq. (9) to produce the following:

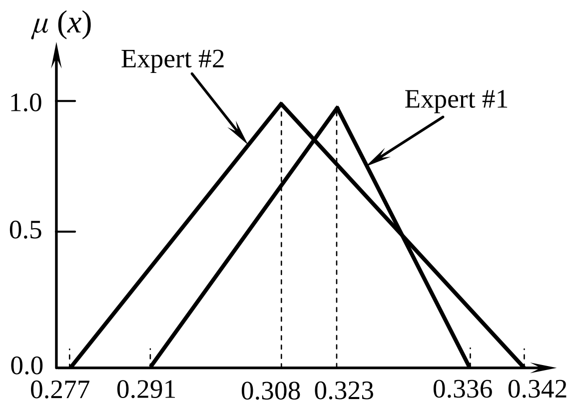


Figure (5): Aggregation of two experts' assessment regarding ***quality***

$$Z_{quality} = \left(\int_{0.291}^{0.323} \frac{1-0}{0.323-0.291}(x-0.291)x dx + \int_{0.323}^{0.336} \left[\frac{0-1}{0.336-0.323}(x-0.323)+1\right] x dx + \int_{0.277}^{0.308} \frac{1-0}{0.308-0.277}(x-0.277)x dx + \int_{0.308}^{0.342} \left[\frac{0-1}{0.342-0.308}(x-0.308)+1\right] x dx \right) \div \left(\int_{0.291}^{0.323} \frac{1-0}{0.323-0.291}(x-0.291) dx + \int_{0.323}^{0.336} \left[\frac{0-1}{0.336-0.323}(x-0.323)+1\right] dx + \int_{0.277}^{0.308} \frac{1-0}{0.308-0.277}(x-0.277) dx + \int_{0.308}^{0.342} \left[\frac{0-1}{0.342-0.308}(x-0.308)+1\right] dx \right) = \mathbf{0.3121}$$

In Buckley's model, [7], fuzzy addition and fuzzy multiplication are used to derive fuzzy weights from group judgment, which are complicated and require considerable computational time. Instead, Nang’s proposed a model which employs the fuzzy maximum and minimum operator and center-of-gravity (COG) techniques because of their simplicity,[3].

Fuzzy max.–min. operator is given by:

$\mu_A(x) = max\{min[\mu_1(x), \mu_2(x), ... \mu_n(x)]\}$ ………………………………... (8)

Where $\mu_A(x)$ is the membership value of the element x in the aggregated subset A; $\mu_1(x), \mu_2(x),...\mu_n(x)$ are membership grades representing the 1^{st}, 2^{nd},…, and n^{th} evaluator's judgment, respectively, (note: in this case $n = 2$).

The COG method is given by the following expression:

$$Z=\frac{\int \mu(z) z dz}{\int \mu(z) dz} \quad (9)$$

Where $\mu(z)$ is the membership value; z is the weighted average. Accordingly, the overallweight of the l^{th} sub-criterion, S_l, can becomputedusing Eq. (10).

By using the foregoing procedures and the two experts'evaluations,in Table3, the weights for **quality**, cost, **safety**, durationand shape yield: (**0.312**, 0.166, **0.251**, 0.136, 0.133), (**0.313**, 0.179, **0.285**,0.141, 0.144), and (**0.311**, 0.139, **0.201**, 0.126, 0.117), regarding α=0,α=0.5 and α=1.0,respectively.

The results indicate that quality andsafety are the two most important main criteria for selecting a bridgeconstruction technique for Tuti – Bahry Bridge; whereas bridge shape hasleastimportance, *notice bolds in the above paragraph*.

Based on the main criteria weights, the overallweights of sub-criterion can beestimated directly by using experts' judgment of sub-criterion shown in Table 4 as follows:

$$S_l = \sum_{i=1}^{L} W_k \times S_{lk} \quad (10)$$

(W_k is the weight of k^{th} main criteria; S_{lk} is the local weight of the l^{th} sub-criterion with respect to the k^{th} main criteria), the results are given in Table 7.

Applying Tables 5 and 7and Eq. (6), thealternative weights can be obtained as shown in Table 8. Consequently,the final alternativeweight can be derived by summing all theweights.

The overall weight of the m^{th} alternative regarding the l^{th} sub-criterion, R_m, is given by, [4]:

$$R_m = \sum_{m=1}^{M} S_l \times R_{ml} \quad (6)$$

The final alternative weight can be derived by summing up all the weights;the weights for Incremental Launching Methodand BalancedCantilever Method are shown in the last two rows of Table 8 for α = 0, 0.5 and 1.0.

Table 7: Over all weights of the sub-criteriafor α= 0, 0.5,1.0(regarding the two experts)

α	Durability	Suitability	Damage cost	Construction cost	Traffic conflict	Site condition
0	0.219	0.092	0.057	0.103	0.139	0.104
0.5	0.221	0.103	0.057	0.103	0.131	0.101
1	0.214	0.089	0.057	0.103	0.145	0.116

Table 7:(*continuous table*)

α	Constructability	Weather condition	Land- scape	Geometry	Environmental preservatives
0	0.093	0.044	0.035	0.055	0.047
0.5	0.088	0.045	0.035	0.056	0.043
1	0.097	0.039	0.035	0.054	0.053

Table 8: Over all weights of the alternatives(for the two experts)

Sub-criteria	Construction Method					
	Incremental Launching			Balanced Cantilever		
α =	**0.0**	**0.5**	**1.0**	**0.0**	**0.5**	**1.0**
Durability	0.081	0.080	0.084	0.134	0.134	0.135

Suitability	0.039	0.035	0.047	0.056	0.053	0.029
Damage cost	0.037	0.037	0.037	0.064	0.063	0.064
Construction cost	0.020	0.020	0.020	0.036	0.036	0.036
Traffic conflict	0.068	0.068	0.068	0.068	0.068	0.068
Site condition	0.065	0.064	0.065	0.039	0.040	0.039
Constructability	0.065	0.064	0.057	0.038	0.035	0.040
Weather condition	0.017	0.017	0.018	0.023	0.022	0.024
Landscape	0.017	0.017	0.017	0.017	0.017	0.017
Geometry	0.020	0.019	0.019	0.025	0.034	0.033
Environmental Preservation	0.020	0.021	0.025	0.028	0.025	0.028
Sum of Weights	**0.449**	**0.442**	**0.453**	**0.537**	**0.527**	**0.513**
Average value		**0.448**			**0.526**	

From Table 8it is clear that the Balanced Cantilever Method (weight = **0.526**) is more appropriate alternative than Incremental Launching Method (weight= **0.448**) for the adoptedcase study of Tuti – Bahry Bridge. It is worthwhile mentioning that the Balanced Cantilever is the method adopted by the contractor and approved by the owner forthe subject Bridge Project.

4. Conclusions

i. Accurately choosing the most suitable bridge construction method is vital for the success of bridges projects. This paper presents application of the Nang fuzzy AHP model to tackle the problem of the AHP model arising from transforming one's imprecise judgment into exact numbers.

ii. Using FAHP model in the selection of a most appropriate bridge construction method indicate that the Balanced Cantilever Method is more suitable for the erection of the new Cable-stayed Bridge connecting Tuti Island withBahry Town in Khartoum State.

iii. Selection process of the superstructure construction method requires high knowledge and experience based on the information on the erection point, surrounding conditions, main characteristics of the bridge, erection machinery and material, which is usually performed based on the objective and subjective judgments of experts in the related bridge site.

iv. Selection the most appropriate bridge construction method.

v. Despite the above, the list of the selected criteria and alternatives may not be an inclusive list in the considered case study. Thus, one may comprise more bridge alternatives, establish more hierarchies or consider the problem in more details.

5. References

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