Application of the Fuzzy Analytical Hierarchy Process in the Assessment of Priority of Bridge Maintenance

Salah Eldin Yousif Hassan, and Eltayeb Hassan Onsa

Abstract—The decision making for performing bridges maintenance might be difficult in presence of various affecting criteria. This paper attempts to apply the Fuzzy Analytical Hierarchy Process in the decision making for bridge maintenance management, on way to help Local Authorities to decide on priority of maintenance between two bridges, in Khartoum State (Sudan), lying along the same corridor and having the same level of distress. The opinion of four experts is pair-wise analyzed for the selection of priority of maintenance. A questionnaire is designed and analyzed using Nang's approach. Weights, from group of evaluations, are analyzed using excel spread sheets developed by the Authors. The outcome of the analysis revealed a logical procedure which successfully utilizes the use of FAHP to promote the decision processes regarding priority of bridges maintenance.

Keywords—Bridge maintenance, Fuzzy hierarchy process.

I. Introduction

THE Ministry of Infrastructures and Transportation (MIT) of Khartoum State (KS) – Sudan, has performed investigations and assessment of two main bridges, namely: the Blue Nile Bridge (BNB) [1] and Burri Bridge (BB) [2]. The results indicated that the level of distress is approximately the same in the two bridges and both bridges are in need for urgent major maintenance. The two bridges, according to the city traffic master plan, are linking Khartoum North with Khartoum across the Blue Nile; each of the two bridges plays special effective role in KS transportation services, see Fig. 1 To allow establishing realistic and effective selection criteria, the extent of influencing function of the bridges connecting Khartoum North with Khartoum are summarized in Table 1. Maintenance information of the BNB and BB is presented Table 2.

Based on the above data it was concluded that closing either of the two subject bridges for priority of maintenance may result in negative impacts to the traffic system in the area and may seriously affect citizens' life. This critical situation let the MIT insists to use precise and measurable method to reach effective decision in: "**which bridge from the two bridges is to be set for maintenance at present time; whereas maintenance of the other bridge to be done later**".

Bearing in mind that: simultaneous maintenance of the two bridges is prohibited in view of tremendous and hazardous traffic problems expected to occur.

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II. Brief Data of Greater Khartoum

Greater Khartoum (32° 32' 53" E, 15° 36' 58" N) is the capital of Sudan and is the main city in Khartoum State. The city is divided into three districts: 1. Khartoum; which is the main political capital of Sudan, characterized by accommodating most of official authorities and administrations, diplomatic representative, public services, commercial banks, and main commercial activities; 2. Omdurman; is the city of heritages with the higher number of population; 3. Khartoum North; is characterized by industrial and agricultural activities, and is a residential city as well, see Fig. 1.

The three districts are isolated from each other by three rivers: the Blue Nile between Khartoum and Khartoum North, the White Nile between Khartoum and Omdurman. Both Blue Nile and White Nile join at Khartoum forming the start of the River Nile which flows between Khartoum North and Omdurman towards north direction. There exist seven bridges as corridors linking between the three districts. Four bridges are linking Khartoum to Khartoum North across the Blue Nile through deferent routs within the main traffic network. The traffic data and beneficial aspects from the four bridges are shown in Table 1. The degree of the beneficial measures is a matter of uncertainty, therefore deciding on which bridge should be closed for maintenance first, considering the recent complicated conditions, is a subject of logical evaluation that can be assessed by intensive judgment and analysis.

III. The Applied Method

The FAHP is defined as mapping of human-being opinion for vagueness and uncertainty into exact numerals. The FAHP proposed by Nang [4] is applied here for bridge maintenance management to assist in avoiding decision that exerts negative impacts in the surroundings. Case study for selecting one from two bridges for priority of maintenance is presented hereinafter.

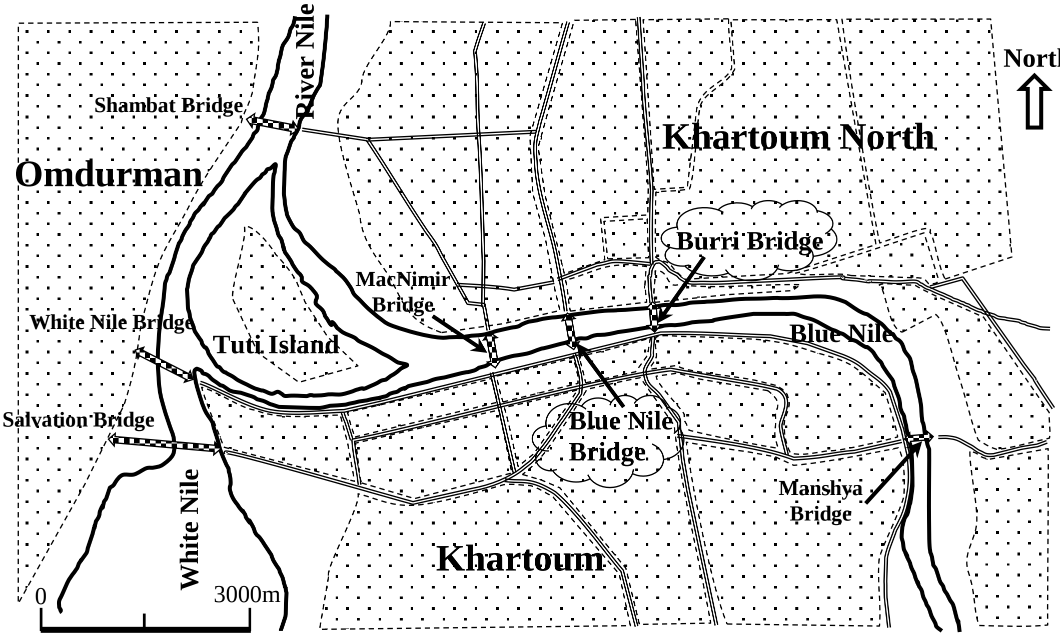

Fig. 1 Location Map

TABLE I
BASIC DATA OF THE FOUR BRIDGES LINKING KHARTOUM WITH KHARTOUM NORTH [3]

No.	Bridge name	Type of superstructure	Recent AADT* (PCUs)	Description of potential aspects
1	Mac Nimir Bridge	Composite, continuous twin steel box girders	53,000	Links Khartoum with Khartoum North; links centers of the two towns.
2	Blue Nile Bridge	Steel truss	40,000	Links Khartoum with Khartoum North through one route extending to the extreme northern extensions where production areas of vegetables and fruits; villagers and local national markets. Main duty free zone and other industrial area; schools and universities. Main railway station. Khartoum University.
3	Burri Bridge	Prestressed concrete cantilever box girder	72,000	Links Khartoum to the main industrial area at Khartoum North and the traffic extends to the east to link vast residential areas. Where the main natural building materials transported from the resources to Khartoum vast districts. The route passes vast residential area to Khartoum industrial area, greater Khartoum marketing zones, to the interstate highways.
4	Manshya Bridge	Twin prestressed concrete box girders	60,000	Links the routes from eastern Khartoum to East Nile Locality at Khartoum North. Note that: it is difficult to detour traffic from other nearby bridges, since this bridges is almost congested by its own traffic and long detouring routs are expected.

**Annual Average Daily Traffic in Passenger Car Units*.

Closing either of the two subject bridges, completely or partially, for maintenance is expected to result in hazardous impacts which differ in magnitude from one decision to another considering the current political, economic and social situation in Khartoum State. The later three aspects are represented in this paper by main criteria and sub-criteria as shown in Table 3.

Two expert engineers, specialized in bridge construction and maintenance, and two town planners were asked to identify possible factors that can affect the final decision through several survey questionnaires. The criteria used in the hierarchy were obtained and checked through the discussion process using Delphi approach [5]. Table 3 illustrates the judgments adopted in the process.

A. Construction of the Hierarchy

Fuzzy AHP decision problem usually consists of the following components [4]:

1. Alternatives, M_i (i = 1, 2 ... m), m = number of alternatives
2. Set of evaluation criterion, C_j (j = 1, 2 ... n), n = number of criteria

TABLE II
MAINTENANCE DATA OF THE BNB AND BB

Bridge name	Allowed traffic	Required maintenance	Cost of maintenance (US Dollars)	Expected Duration of maintenance
Blue Nile Bridge	Trains, minibuses and private cars	Strengthening cross girders and stringers. Strengthening approach plate girder spans. Painting the all steel members. Strengthening the cylindrical piers and piers bracings. Widening Walkway to traffic lane width. Removing and replacing the bridge paving concrete and asphalt after checking steel troughing. Changing the expansion joints. Repairing and. Install new lightening system and traffic furniture.	10,000,000	16 Months
Burri Bridge	All kinds except train	Repair and seal cracks in the box girders and diaphragms. Strengthen the 12 cantilever box girders in six spans by external additional Prestressing. Remove and replace sidewalk. Replace expansion joints. Replace paving. Erect new lightening system. Correct camber of the bridge deck	10,000,000	22 Months

TABLE III
EFFECTIVE CRITERIA FOR SELECTING ONE FROM TWO BRIDGES FOR PRIORITY OF MAINTENANCE

No.	Criterion	Notation	Sub-criteria	Reason for impact
1	Cost	C_1	Maintenance cost Detouring cost	High maintenance cost and expensive traffic detouring processes will affect the treasury
2	Time duration	C_2	Environmental impact Political impact	Posting a bridge for long period will exert district pollution. By closing the roads and intersection; politicians may respond to public claims and may enforce stopping maintenance processes.
3	Traffic impact	C_3	Site traffic City traffic	The adjacent traffic may cause maintenance ineffectiveness and the site workers might be in unsafe situation. City traffic network may collapse.
4	Security and emergency	C_4	Public security Emergency	Impossibility to secure the towns and difficulty in moving ambulances, and other emergency vehicles, equipment and workers. Nearby prison and military premises.
5	Economy	C_5	General economy Mobile economy	National production may partially decline, citizens who drive mobile economy may slightly minimize daily rush. Commercial activities may depreciate and the economy may be weakened.

3. Linguistic judgment, r_{ij}, representing the relative importance of each pair criteria, and
4. Weighting vector, W_i (i = 1, 2 ... n), n = number of criteria.

The first step in applying the FAH models is to determine the entire important criteria and their relationship to the decision problem in the form of a hierarchy as shown in Fig. 2. This step is critical because the selected criteria can seriously influence the final choice. The hierarchy is structured from the top levels (the overall goal of the problem: i.e. selection of the most desirable bridge to be maintained first) through intermediate levels (main criteria and sub-criteria) to the bottom level (the list of alternatives)

Five linguistic variables are described by fuzzy numbers denoted by Nang [4] as shown in Table 4. 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*). The α-cut concept is applied; in practical application α = 0, 0.5 and 1.0 are used to indicate the decision making condition that has pessimistic, moderate and optimistic view, respectively [6].

Nang's approach employs triangular and trapezoidal fuzzy numbers and the α-cut concept to deal with the imprecision inherent to the process of subjective judgment [4], [7] see Fig. 3: triangle LNR and trapezoid LMOR. Note in Fig. 3: The vertical axis represents membership values of element x in the α-cut; L, X_{aM} and R being the left, middle and right fuzzy numbers for the triangular α-cut, respectively; L, X_{aL}, X_{aR} and R being the two left and two right fuzzy numbers for trapezoidal α-cut.

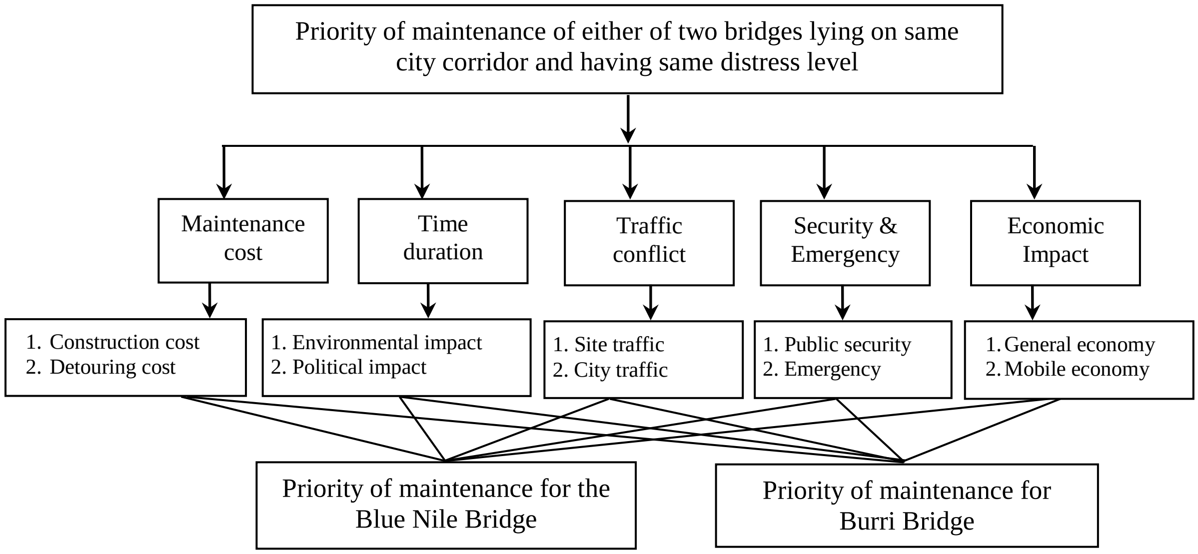

Fig. 2 Hierarchy flow chart

TABLE IV
FUZZY IMPORTANCE SCALE*

Linguistic 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 "Very Important" are represented by half trapezoidal membership functions; whereas the remaining levels are characterized by symmetric triangular membership functions* [4].

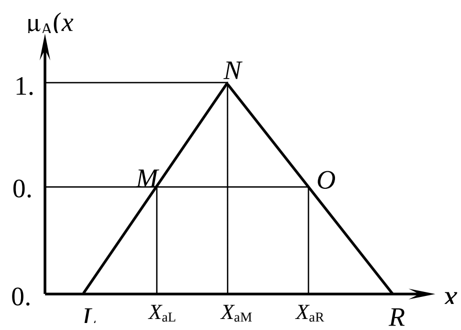

Fig. 3 Triangular and trapezoidal fuzzy intervals under α – cut.

B. Case study review

Both the Blue Nile Bridge and Burri Bridge were recently inspected and evaluated by the MIT. Investigation results indicated that both bridges are in need for urgent repair [1], [2]. The MIT attempted to choose the bridge which is expected to result in less negative impacts when closed partially or completely for maintenance works before the other bridge. The FAHP suggested by Nang [4] is modified and applied here as follows:

i. Four experts (two bridge engineers and two town planners) 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 [8], [9].
ii. **Five** main criteria and **ten** sub-criteria were adopted for this case study, as shown in Table 3.
iii. Once the hierarchy was established, the opinion of the assigned experts was obtained via questionnaires designed and used for direct pair-wise comparison and judgment.
iv. All possible pair-combinations of experts are examined and analyzed, see Table 5.

TABLE V
PAIR-COMBINATIONS OF THE EXPERTS

Combination No.	Pair-Combination
1	Expert 1 *with* Expert 2
2	Expert 2 *with* Expert 3
3	Expert 1 *with* Expert 3
4	Expert 3 *with* Expert 4
5	Expert 1 *with* Expert 4
6	Expert 2 *with* Expert 4

http://dx.doi.org/10.15242/IIE.E0914066

The assessment results by the four experts are shown in Tables 6 to 8.

TABLE VI
EVALUATION RESULTS OF THE MAIN CRITERION WITH RESPECT TO THE OVERALL GOAL

Pair-wise criteria	Opinion of expert #1	Opinion of Expert #2	Opinion of expert #3	Opinion of Expert #4
Cost *versus* Duration	EI	EI	LI	LI
Cost *versus* Traffic	VU	LI	VU	LI
Cost *versus* Security	VU	VU	LI	EI
Cost *versus* Economy	EI	MI	VU	EI
Duration *versus* Traffic	LI	VI	VI	VI
Duration *versus* Security	VU	LI	VI	VI
Duration *versus* economy	LI	EI	MI	VI
Traffic *versus* Security	VU	LI	VI	VI
Traffic *versus* Economy	EI	EI	MI	MI
Security *versus* Economy	VI	MI	EI	VI

TABLE VII
EVALUATION OF THE SUB-CRITERIA WITH RESPECT TO THE MAIN CRITERIA FOR THE FOUR EXPERTS

Pair-wise criteria	Opinion of expert #1	Opinion of expert #2	Opinion of expert #3	Opinion of expert #4
Maintenance cost ***versus*** Detouring cost	VI	MI	VU	EI
Environment impact ***versus*** Political impacts	VU	EI	VI	VU
Site traffic ***versus*** City traffic	MI	EI	EI	EI
Public security ***versus*** Emergency services	MI	EI	MI	VI
General economy ***versus*** Mobile economy	VU	EI	EI	EI

TABLE VIII
ASSESSMENT RESULTS FOR THE ALTERNATIVES WITH RESPECT TO THE SUB-CRITERIA

Criteria	Sub-criteria	Opinion of expert #1	Opinion of expert #2	Opinion of expert #3	Opinion of expert #4
Cost	Maintenance cost[1]	VU	MI	LI	EI
	Maintenance cost[2]	VU	LI	VU	EI
	Detouring cost[1]	VU	EI	VU	VI
	Detouring cost[2]	VU	EI	LI	VI
Duration	Impact on environment[1]	MI	MI	LI	MI
	Impact on environment[2]	MI	LI	LI	MI
	Political impacts[1]	VI	EI	VI	VI
	Political impacts[2]	VI	EI	VI	VI
Traffic Impact	Site traffic[1]	VI	MI	MI	VI
	Site traffic[2]	EI	LI	VI	MI
	City traffic[1]	VI	VI	LI	MI
	City traffic[2]	LI	VU	EI	VI
Security	Public security[1]	VI	MI	LI	EI
	Public security[2]	VI	LI	EI	VI
	Emergency[1]	LI	EI	LI	VI
	Emergency[2]	LI	EI	LI	VI
Economy	General economy[1]	VU	MI	VI	EI
	General economy[2]	VU	LI	EI	VI
	Mobile economy[1]	VI	EI	MI	MI
	Mobil economy[2]	EI	EI	EI	VI

Note:
Superscript [1]: *Denotes the relative importance degree for the option of giving the priority of maintenance to the Blue Nile Bridge.*
Superscript [2]: *Denotes the relative importance degree for the option giving the priority of maintenance to Burri Bridge.*

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C. Calculation of weights

The opinion of the four experts is aggregated. Next, the geometric mean of cost (C_1) with regard to duration (C_2), traffic (C_3), security (C_4), and economy (C_5) are calculated as follows:

Applying Equation (7) in reference [4], the fuzzy comparison matrix based on the judgment of expert #1, regarding the main criterion with respect to the overall goal in Table 6 and fuzzy number in Table 4 will be as follows:

$$A_1=\begin{bmatrix} 1 & 3,5,7 & 0,0,1,2 & 0,0,1,2 & 3,5,7 \\ 3,5,7 & 1 & 1,2.5,4 & 0,0,1,2 & 1,2.5,4 \\ 8,9,10,10 & 6,7.5,9 & 1 & 0,0,1,2 & 3,5,7 \\ 8,9,10,10 & 8,9,10,10 & 8,9,10,10 & 1 & 8,9,10,10 \\ 3,5,7 & 6,7.5,9 & 3,5,7 & 0,0,1,2 & 1 \end{bmatrix}$$

Hence, the upper-bound comparison matrix for judgment of expert #1 will be:

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

The local weight, W_i, of criterion i is given by:

$$W_i = g_i / \sum_{i=1}^{n} g_i \quad (1)$$

Where,

n = total number of criteria,

g_i = geometric mean of criterion i, given by:

$$g_i = \left(\prod_{j=1}^{n} r_{ij}\right)^{\frac{1}{n}} \quad (2)$$

$\therefore g_1 = (1\times7\times 2\times2\times7)^{1/5} = 2.87376$

The calculations for $g_2 \ldots g_5$ are similar to g_1.

Similarly, the geometric mean for C_2, C_3, C_4, and C_5 yields 2.95155, 4.16941, 6.30957, and 3.88234, respectively. Hence, the relative weight of C_1 can be estimated by using (1) to get:

W_{U1} = 2.87376/ (2.87376+2.95155+4.16941+6.30957+3.88234) = 0.14236

Similarly the weights regarding C_2, C_3, C_4, and C_5 can be obtained; the result is shown in the following matrix:

$$W_{U1} = \begin{bmatrix} 0.14236 \\ 0.14621 \\ 0.20655 \\ 0.31256 \\ 0.19232 \end{bmatrix} \quad (3)$$

Thus the weights at different levels: (Low, Medium, Upper) should be calculated for all criteria for the four experts' opinions.

Similarly values of W_{U2}, W_{U3}, W_{U4} and W_{U5} can be obtained; note that W_i is the i^{th} criterion's weight, where W_i > 0, and $\sum_{i=1}^{n} W_i = 1$.

For each of the four experts the weight of the selected criterion are applied using (1) and (2) at the three levels of judgment: Lower (L), Medium (M), and upper level (U). Table 9 shows the results of the local weights of the five main criteria.

Using (3), the aggregate of the two experts' evaluations can be obtained as shown in Fig. 4. Thus, the representative weight of quality (C_1= 0.3121) can be found using (4) and Fig. 4, See calculations below:

For the group evaluation, it is required to aggregate manifold evaluators' opinions into one number (= **0.11174** for cost, see (8)). The aggregate of multiple experts' evaluations encompasses a range of membership values that must be defuzzified in order to resolve a single representative value.

In Buckley's model [6], [8] fuzzy addition and fuzzy multiplication are used to derive fuzzy weights from group judgment, which are complicated and require considerable computational time. Instead, the model proposed by Nang employs the fuzzy maximum and minimum operator and center-of-gravity (COG) techniques because of their simplicity [4].

TABLE IX
ASSESSMENT RESULTS FOR THE ALTERNATIVES WITH RESPECT TO THE SUB-CRITERIA

Criterion	Level	Expert #1	Expert #2	Expert #3	Expert #4
Cost	L	0.11939	0.14060	0.07897	0.12150
	M	0.12090	0.13351	0.09253	0.17593
	U	0.14236	0.16295	0.11962	0.18950
Duration	L	0.09584	0.17249	0.18552	0.30875
	M	0.12641	0.18552	0.30764	0.35820
	U	0.14621	0.21381	0.34581	0.39013
Traffic Impact	L	0.20346	0.16295	0.20119	0.21911
	M	0.20655	0.20119	0.22297	0.22256
	U	0.20787	0.20718	0.23112	0.14300
Security	L	0.31256	0.27804	0.13241	0.13715
	M	0.36832	0.33346	0.14698	0.14783
	U	0.40606	0.35029	0.35029	0.15424
Economy	L	0.17084	0.12240	0.12240	0.09753
	M	0.18090	0.15336	0.19812	0.10616
	U	0.19232	0.18224	0.20279	0.12841

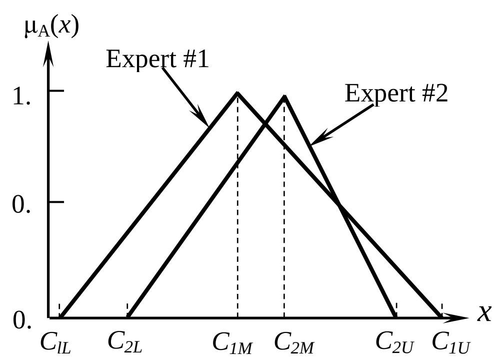

Fig. 4 Aggregation of every two experts' membership

Fuzzy maximum – minimum operator is given by:

$$\mu_A(x) = max\{min[\mu_1(x), \mu_2(x),\ldots,\mu_2(x)]\} \quad (4)$$

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, see Fig. 4.

The COG is given by the following expression:

$$Z = \frac{\int \mu(z) z dz}{\int \mu(z) dz} \quad (5)$$

Where *(z)* is the membership value; z is the weighted average. The overall weight of the l^{th}sub-criterion, S_l, are computed as follows:

$$S_l = \sum_{i=1}^{L} W_k \times S_{lk} \quad (6)$$

Where W_k is the weight of k^{th} main criteria and S_{lk} is the local weight of the l^{th} sub-criterion with respect to the k^{th} main criteria).

The overall weights of l^{th} sub-criterion are estimated directly by using experts' judgment of sub-criteria shown in Table 6 as follows:

Applying Tables 6 and 7 and Eq. (6), the alternative weights are obtained as shown in Table 10. Consequently, the final alternative weight is derived by summing all the weights. The overall weight, R_m, of the m^{th} alternative regarding the l^{th} sub-criterion is given by the following equation [4]:

$$R_m = \sum_{m=1}^{M} S_l \times R_{ml} \quad (7)$$

Hence, the COG for cost is given by (8):

$$\begin{aligned} Z_{cost} = & \left(\int_{0.11939}^{0.12090} \frac{1-0}{0.12090-0.11939}(x-0.11939)x dx + \int_{0.12090}^{0.14236} \left[\frac{0-1}{0.14236-0.12090}(x-0.12090)+1 \right] x dx \right. \\ & \left. + \int_{0.14061}^{0.13351} \frac{1-0}{0.13351-0.14061}(x-0.14061)x dx + \int_{0.13351}^{0.16295} \left[\frac{0-1}{0.16295-0.13351}(x-0.13351)+1 \right] x dx \right) \\ & \div \left(\int_{0.11939}^{0.12090} \frac{1-0}{0.12090-0.11939}(x-0.11939) dx + \int_{0.12090}^{0.14236} \left[\frac{0-1}{0.14236-0.12090}(x-0.12090)+1 \right] dx \right. \\ & \left. + \int_{0.14061}^{0.133508} \frac{1-0}{0.13351-0.14061}(x-0.14061) dx + \int_{0.13351}^{0.16295} \left[\frac{0-1}{0.16295-0.13351}(x-0.13351)+1 \right] dx \right) \\ & = \mathbf{0.11174} \end{aligned} \quad (8)$$

The COG, Z, of the opinion weight of every two experts is calculated under the α-cut concept according to Nang's enhancement to Buckley model [4], [6] where $\alpha = 0$, 0.5, and 1 for the different levels of local weights.

By using the foregoing procedures and the four experts' evaluations the weights for cost, duration, traffic, security and economy yielded the values shown in Table 10 for Experts 1 and 2.

The final alternative weights are derived by summing up all the weights; the sum of weights for giving priority of maintenance to the BNB and the sum of weight for priority of maintenance to BB are shown in the row before last in Table 10 for $\alpha = 0$, 0.5 and 1.0. Average weights are shown in the last row.

IV. Summary Tables Of Results

The following Table 11 shows the reliable result from which the MIT can decide in which bridge maintenance works can be started as alternative with the least negative impacts. When comparing judgments of Expert #1 with judgments of Expert #2 the results in Table 10 indicate that starting maintenance of BB will result in less negative impacts (average weight for BB = 0.3894 less than average weight of the BNB = 0.5624)

Similarly, the overall weights of the alternatives with respect to judgment of Experts 2 and 3, Experts 1 and 3, Experts 2 and 3, of Experts 3 and 4, and Experts 1 and 4 are calculated; the results of average weights are given in Table 11. Note that alternative with respect to judgment of Experts 2 and 4 is omitted because it is not expected to change the decision since 4 out of 5 tested combinations of experts indicated priority of maintenance to BB will result in less negative results regarding the adopted criteria; the best judgments (maximum average weights) are shown **bold** in Table 11.

TABLE X
OVERALL WEIGHTS OF THE ALTERNATIVES WITH RESPECT TO JUDGMENT OF EXPERTS #1 AND 2

Criteria	Blue Nile Bridge			Burri Bridge		
	α = 0	α = 0.5	α = 1	α = 0	α = 0.5	α = 1
Maintenance cost	0.0600	0.0591	0.0599	0.0329	0.0328	0.0340
Detouring cost	0.0220	0.0223	0.0223	0.0223	0.0223	0.0220
Environmental impact	0.0320	0.0319	0.0306	0.0222	0.0215	0.0250
Political impact	0.0450	0.0446	0.0446	0.0446	0.0446	0.0450
Site traffic	0.0620	0.0615	0.0621	0.0376	0.0376	0.0380
City traffic	0.0490	0.0491	0.0492	0.0214	0.0205	0.0220
Public security	0.1380	0.1371	0.1389	0.0765	0.0765	0.0770
Emergency services	0.0620	0.0623	0.0623	0.0623	0.0623	0.0620
General economy	0.0340	0.0343	0.0344	0.0186	0.0185	0.0190
Mobile economy	0.0590	0.0596	0.0582	0.0493	0.0489	0.0510

Sum of weights	**0.5630**	**0.5618**	**0.5625**	**0.3877**	**0.3855**	**0.3950**
Average weight		**0.5624**			**0.3894**	

TABLE XI
AVERAGE WEIGHT OF PAIR-WISE JUDGMENT OF THE FOUR EXPERTS

Bridge Name	Average alternative weight with respect to each pair of expert judgment				
	Experts #1 and 2	Experts #2 and3	Experts #1 and3	Experts #3 and4	Experts #1 and4
BNB	**0.56240**	**0.56550**	**0.61087**	0.49906	**0.59350**
BB	0.38940	0.42486	0.55317	**0.52192**	0.46840

V. DISCUSSION OF RESULTS

Five models of membership were analyzed to test, in pairs, four experts' judgment on way to achieve refined and reliable result. The total alternative weights with respect to the main criteria and sub-criteria, reached by the analyses of experts' judgment using FAHP, has the follow indications:

1. The total weight of each of the two alternatives with respect to the main criteria and the sub-criteria, when analyzing each pair of the experts using alternate modules of all possible pair combinations between the four experts, revealed four modeled membership agreed to the priority of maintenance to Burri Bridge. Only one model of membership agreed to the priority of maintenance to the Blue Nile Bridge.

2. The results also indicated that the effect of maintenance cost, detouring cost, and mobile economy slightly affected the decision. While public security, site traffic and political impact are the major influencing factors in the decision. The above fact was clearly notices when the outcome from this study is implemented on site.

3. The four Modules in the applied FAHP indicated that starting Burri Bridge maintenance first shall come with least impacts than the other alternative. This fact successfully agrees with the on-going maintenance processes. It is worthwhile mentioning that based on the findings from this research, maintenance of BB is already started. Maintenance works and nearby traffic are ongoing smoothly; work is expected to finish by end of this year (2014).

4. The results also ascertained that the helping information and data summited to the four experts are enough and useful in achieving best judgments.

5. The results verified that the proposed criteria and sub-criteria successfully meet the requirements of the subject case study for judgment, note the close weight values obtained.

VI. CONCLUSIONS

The following conclusions are drawn from this study:

1. Political impact, site traffic, and city traffic are the most criteria affecting the decision making in the priority of maintenance of the subject two bridges.

2. Starting maintenance and rehabilitation works of Burri Bridge took the priority of maintenance according to the FAHP analyses conducted on this research. The three utmost affecting criteria are: traffic, emergency and political impact which are proved to be the most realized criteria from notices on the ongoing maintenance works on BB.

3. Taking opinion of experts in bridge engineering as well as opinion of planners revealed consistent results: as it is noticed that bridge engineers are usually having acknowledged information about other different relevant life aspects, including planning; hence opinion of bridge engineers is found to be in close agreement to planners' opinion.

4. Actions on many technical issues regarding inspection and maintenance of existing bridges and construction of new bridges in Khartoum State were mostly taken through formed technical committees where verbal arguments usually guide to final decisions, i.e. analytical guidance and technical processes are usually absentee. Therefore, a method that shall render many results to be built upon non-linguistics, and the follow-up procedure seems to be difficult.

5. There are many aspects in other public life aspects where the decision making is to be made according to precise investigations and studies, the FAHP when used as guidance to such decisions will result in beneficial outcome. Hence, many of such decisions can be created based on analytical and measureable bases.

REFERENCES

[1] Ministry of Infrastructures and Transportation. "Evaluation of the Blue Nile Bridge" Report prepared by China JILIN Company & Beijing University of Civil & Architecture Engineering, 2009.

[2] Ministry of Infrastructures and Transportation. "Test Repot of Burri Bridge", Report prepared by China Heilong Jiang Roads & Bridges Construction Company. March 2005.

[3] Ministry of Infrastructures and Transportation. "Sudan Bridges Records", Khartoum State, Sudan, 2013.

[4] Nang-Fei Pan. "Fuzzy AHP approach for selecting the suitable bridge construction method". Automation in Construction 17 (2008) 958–965. http://dx.doi.org/10.1016/j.autcon.2008.03.005

[5] Linstone. H. A. Turoff. M., "The Delphi method, techniques and application" Addison-Wesley, London, 1975.

[6] Buckley, J. J, "Fuzzy Hierarchical Analysis", Fuzzy Sets and Systems, 17, 233-247, 1985 http://dx.doi.org/10.1016/0165-0114(85)90090-9

[7] Abdelfazl Zarei Babak Maleki. "Using Fuzzy, Delphi Method in AHP to select optimum", Department of Industrial Engineering, Iran University of Science and Technology, 2010.

[8] Hashim M. A. and Onsa, E. H. "Effect of the Construction Method on the Cost and Duration of Bridge Projects in Sudan". Proceedings of the International Conference on Engineering UBI2013 Nov. 2013 – University of Beira Interior – Covilhã, Portugal.

[9] Saaty, T. L. "The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation" McGraw Hill, NY, 1980.