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Fuzzy Analytical Hierarchy Process (FAHP) for evaluating knowledge areas of Advanced Certificate in Engineering taught in South Africa

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ABSTRACT

In order to evaluate the consistency of the knowledge areas (KAs) covered in the advanced certificate in engineering (AdvCertEng) course, this study used the Fuzzy Analytic Hierarchy Process (FAHP) technique. Both universities of technology and comprehensive universities in South Africa offer this subject. The primary requirements that an engineering programme should meet for the purposes of creating and implementing FAHP, are knowledge areas. The opinions of experts and decision-makers are prone to some subjectivity, imprecision, even some uncertainty and ambiguity, which results in fuzziness. Triangular fuzzy numbers (TFN1) between (1,1,1) and (9,9,9) are used to establish fuzzy pairwise comparisons between criteria on a qualitative level, whilst FAHP is used to calculate the weights of the criterion on a quantitative one. In this investigation, TFNs linked to a fuzzy distance from the crisp values of 1 are employed, and the related FAHP is denoted as FAHP1. The credit weight for each knowledge area is then calculated uniformly using the same method. AdvCertEng's existing knowledge area credit weights were generally confirmed using FAHP1. FAHP and ECSA's credit weights did, however, differ by minuscule amounts.

Keywords: Fuzzy Analytic hierarchy, knowledge areas, engineering qualification, credit allocation

1. INTRODUCTION

Engineering curriculum instruction and learning in South African institutions are based on knowledge areas (KAs). Six components make up KAs: engineering sciences (A), mathematical sciences (B), design and synthesis (C), natural sciences (D), complementary studies (E), and for relocation (F) [1]. The Higher Education Framework's [3] credit allocation is linked to these KAs. For the student to meet learning objectives, 10 hours of learning are equivalent to one credit. Engineering Council of South Africa (ECSA) serves as the accrediting organisation for engineering programmes at several universities throughout South Africa. Therefore, it is crucial for ECSA to ensure that programmes are in line with South Africa's National Qualifications Framework (NQF).

Typically, credit distribution is expressed quantitatively by the ECSA decision-making team in charge of education and training. When allocating credit among knowledge areas, the possibility of some subjectivity, ambiguity, or imprecision cannot be completely ruled out. When each university is free to establish engineering courses based on its own preferences, this may be made worse. A degree of subjectivity, uncertainty, or vagueness may be present in the way that engineering programmes distribute credit for knowledge areas or domains (specifically, major criteria). To do so, multi-criteria decision making (MCDM) methods like FAHP are frequently used to address complex challenges [2], which are characterised by a degree of uncertainty and ambiguity in experts' perspectives. The capacity of FAHP to handle the aforementioned qualities is considered to be a benefit of this method over the conventional Analytic Hierarchy Process (AHP). FAHP has been used in a number of different disciplines [3-6]. It is extremely rare in the current literature to use FAHP as an MCDM method to evaluate the consistency of the knowledge domains and derive the weights. Fuzzy Triangular Numbers (TFN) [2] are unquestionably more popular than other fuzzy numbers in the development of FAHP. To do so, FAHP, designated as FAHP1, will utilise TFN1, specifically adopting the fuzzy distance of 1 from the crisp values in the likert scale as in [7]. In many cases, where the consistency ratio of the fuzzy decision matrix is less than

10%, expert opinions are appropriate. Crisp values, which correspond to the middle number of TFNs, can be sufficient to determine consistency [7]. On the TFN1-assigned Likert scale, which ranges from 1 to 9, the qualitative level of preference between 2 items is evaluated. As a result, TFN1 is represented as a triplet (Xl, Xm, Xu) whose components are, respectively, lower, middle, and upper values. In terms of the quantitative aspect, the fuzzy decision matrix consistency is examined before the weights of the criteria and alternatives are established. The knowledge areas offered by ECSA for the engineering technology credentials taught in South African universities are used to tailor FAHP in the current study. The terms "model," "methodology," "tool," and "technique" can all be used interchangeably throughout the remainder of the paper, as can "decision matrix," "pairwise comparison matrix," and "judgement matrix." It is possible to eliminate the words "engineering" and "fuzzy" before the words "programme," "pairwise comparison," and "judgement matrix" or "decision matrix," respectively. Course, programme, and qualification are all interchangeable terms. “Knowledge area” and “knowledge domain” will mean the same. The remainder of the research will be organised as follows. The overview of FAHP1 and its applicability to the knowledge domains of engineering qualification are covered in Section 2. The data used and the methodical procedure required to carry out FAHP are covered in Section 3. Section 4 displays the discussions and findings. Section 5 covers the conclusions of the study.

2. FOUNDATION OF FAHP AND KNOWLEDGE AREAS OF ENGINEERING PROGRAMMES

The conventional or normal AHP approach and its variations, such as the FAHP category, have seen a wide range of uses since its debut in the early 1980s [8] for situations involving multi-criteria decision making, as indicated in the previous section. Since the normal AHP does not adequately address the imprecision and fuzziness of expert opinions, the fuzzy set theory proposed in [9] was coupled with AHP to create FAHP. Fuzzy AHP is thus appropriate for MCDM issue scenarios involving uncertainty, ambiguity, and imprecision. This is just one benefit of FAHP over AHP. Despite this benefit, the use of FAHP for purposes such as consistently assessing the knowledge areas required for engineering credentials is hardly ever reported. FAHP reduces a complex problem to a simpler one by breaking it down into three basic levels: setting the aim, establishing the criteria and sub-criteria, and evaluating the alternatives. When employing the fuzzy AHP technique, pairwise comparisons are made by determining which items (such as criteria and alternatives) are preferred using a triangle fuzzy number with middle crisp points on a likert scale from 1 to 9. According to Table 1, the scale's odd numbers (1 to 9) range from similarly important to extremely important. In theory, a fuzzy AHP survey in the form of an interview or a written questionnaire is created to gather the opinions of experts regarding the relative importance of different decision-making elements.

Table 1. Likert scale (1-9) for level of importance of FAHP model and their reciprocals

Level of preference	Description	TFN1	Reciprocals of levels of preference
1	Two elements are equally important	1,1,1	1/1/1
3	One element is moderately important over the other	2,3,4	1/4,1/3,1/2
5	One element is strongly more important over the other	4,5,6	1/6,1/5 ,1/4
7	One element is very strongly more important over the other	6,7,8	1/8,1/7,1/6
9	One entity is extremely more important over the other	9,9,9	1/9 ,1/9,1/9
2,4,6,8	Intermediate values between the above preferences	1,2,3: 3,4,2: 5,6,7: 7,8,9	1/3,1/2,1: 2/5,1/4,1/3: 1/7,1/6,1/5: 1/9,1/8,1/7

If two factors are equally important, the fuzzy pairwise comparison yields a score of (1,1,1). If one aspect is significantly more important than the other, as indicated in the table above, the score (2,3,4) is given to the judgement. The intermediate importance levels are represented by the fuzzy scores (1,2,3), (3,4,5), (5,6,7), and (7,8,9). Similar to the normal AHP, the fuzzy decision matrix can be determined for each level of the hierarchy. This matrix makes it possible to determine both the final weights and the fuzzy weights for the criterion, sub-criteria, and alternatives.

These operations are performed on fuzzy numbers:

Given 2 TFNs Y1 = $(Yl1, Ym1, Yu1)$ and
Y2 = $(Yl2, Ym2, Yu2)$
-Addition
$Y1 \oplus Y2 = (Yl1 + Yl2, Ym1 + Ym2, Yu1 + Yu2)$
-Subtraction
$Y1 \ominus Y2 = (Yl1 - Yl2, Ym1 - Ym2, Yu1 - Yu2)$
-Multiplication
$Y1 \otimes Y2 = (Yl1 \times Yl2, Ym1 \times Ym2, Yu1 \times Yu2)$
-Inverse
$Y1 = (1/Yu1, 1/Ym1, 1/Yl1)$
Where:
Y1 is the initial triangular fuzzy number.
Y2 is the last triangular fuzzy number.
Ym is the mode of the initial/last TFN.
$Yl1/2$ is the lowest limit of the initial/last TFN.
$Yu1/2$ is the highest limit of the initial/last TFN.

3. DATA AVAILABILITY AND METHODS

Knowledge domains were understood as criteria for FAHP1 development and execution. FAHP1 was created using the ECSA document, which was published on its website and adopted in engineering technology programmes. From the ECSA publication, KAs of AdvCertEng were extracted and presented in Table 2. This programme consists of at least 140 credits distributed throughout the KAs. The minimum credits, or 1400 notional hours, are the basis from which the weights of the KAs are generated. The ECSA team's distribution of credit came about because of a consultative process and an alignment of best practises with the many accords to which ECSA belongs.

Table 2. Knowledge areas minimum credits of Advanced Certificate in Engineering as adapted from ECSA

	Knowledge area	Minimum credits	Calculated weights from minimum credits (%)
T	Engineering sciences	35	25
S	Mathematical sciences	7	5
W	Design and synthesis	35	25
X	Natural sciences	7	5
Y	Complementary studies	7	5
Z	For Relocation	49	35
	Total	140	100

As seen in the table above, a letter is given to each knowledge area. Hence, for the rest of the paper, the letters T, S, W, X, Y and Z could be used for their knowledge areas respectively. It is not always appropriate to rely solely on the conventional AHP technique to extract the criteria weights from fuzzy matrices due to its incapacity to deal with imprecision and ambiguity. As a result, FAHP1 was employed to find any fuzziness that might be produced during the distribution of credits for the AdvCertEng qualification's knowledge areas. When making fuzzy pairwise comparisons, a triangular fuzzy number (TFN1) was employed to represent the relative level of importance. A fuzzy decision matrix was created to combine these. The fuzzy weights of the criteria were calculated using the geometric means of the matrix entries. The fuzzy weights were defuzzified into crisp weights using the centre of area (COA) method.

The steps to create and put into practice FAHP1 are listed below based on the goal of this study.

Criteria are used to express the knowledge domains' structural hierarchy. As a result, it is a two-level hierarchy based on the objective and the various knowledge domains. The objective was to rank the various knowledge areas while taking into account the degree of accuracy in credit allocation and the existing credit allocation criteria. The primary purpose of the study is to examine the criteria. There isn't any other option.

The linguistic variables produced from the ratio technique among the criteria described in the prior paper were used to establish fuzzy pairwise comparisons [11]. In this manner, the matching TFN1 was determined using the Likert scale. The fuzzification process begins at this stage. Given that T and Y each has 14 credits, the ratio is 1:1, and using the ratio technique, T and Y are given the TFN1 (1,1,1) during pairwise comparison because they are both equally important. Since the ratio between Z and S is 7:1, Z may be significantly more important than S, but TFN1 is (6,7,8). For instance, the reciprocal of TFN1, or (1/8,1/7,1/6), is utilised when comparing S to Z. For the remaining knowledge domains, a similar fuzzy pairwise comparison procedure is used.
Therefore, each paired comparison matched a triangular fuzzy number.

According to a companion work [10], the consistency ratio (CR), which is the ratio between the consistency index (CI) and the random index (RI), was computed to assess the correctness of the fuzzy judgement matrix. CR ought to be under 10%.
The TFN is typically used with the crisp value as the middle value.
Table 3 below lists the consistency index values for the fuzzy judgement matrix's various sizes.

Table 3. Random index representing different sizes of pairwise comparison matrix.

n	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41

The resultant fuzzy pairwise comparison matrix was used to calculate weights, once the consistency test had been passed. When the correlation ratio (CR) is 0.1 [12] or somewhat higher, errors in the weight determination can be tolerated in the results.

These steps [7] were used to calculate the fuzzy weights:

- Calculating each criterion's geometric mean for the fuzzy comparison elements. Each requirement corresponds to a vector called a TFN1.
- The fuzzy vector summation is obtained by adding the members of the same category for each vector individually.
- Calculating the (-1) power of the summation vector and then replace TFN1 to create the rising order. Consequently, the reverse vector was acquired. Discovering the fuzzy weight for each condition that is multiplied by this reverse vector.
- The centre of area technique was used to defuzzify the weight criterion, which means that for a given fuzzy weight Yi [Yli, Ymi, Yui], Equation (1) below was used to produce the nonfuzzy weights.

$$\mathrm{Y}iD=1/3[\mathrm{Yli}+\mathrm{Y}mi+\mathrm{Y}ui] \tag{1}$$

YiD is the defuzzified weight and i=1,..., n (n is the number of criteria) are present.

Furthermore, the nonfuzzy weights could be normalised.
In order to validate the weights, disparities between the weights assigned by ECSA and the weights decided by using AHP were compared. The better the outcomes, the smaller the differences. As a general rule, it was first thought to be an arbitrarily small relative difference of no more than 10%.

4. RESULTS AND DISCUSSION

Determination of fuzzy decision matrix and consistency test

The decision matrix was obtained from the fuzzy pairwise comparisons among the knowledge areas, as presented in Table 4. The matrix size is 6. It is recalled this matrix captured the ECSA team’s opinions on the knowledge areas of the Advanced Certificate.

Table 4 Fuzzy decision matrix

	T	S	W	X	Y	Z
T	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	(1/3,½,1)	(1,1,1)	(1/5,1/4,1/3)
S	(1/3,1/2,1)	(1,1,1)	(1/6,1/5,1/4)	(1/5,¼,1/3)	(1/3,1/2,1)	(1/8,1/7,1/6)
W	(2,3,4)	(4,5,6)	(1,1,1)	(1,1,1)	(2,3,4)	(1/3,1/2,1)
X	(1,2,3)	(3,4,5)	(1,1,1)	(1,1,1)	(1,2,3)	(1/3,1/2,1)
Y	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	(1/3,½,1)	(1,1,1)	(1/5,1/4,1/3)
Z	(3,4,5)	(6,7,8)	(1,2,3)	(1,2,3)	(3,4,5)	(1,1,1)

From the previous study [11], the maximum eigen value and the consistency ratio were obtained for crisp values. These are middle values of TFN1. The value of CR<10 % derived from the matrix of crisp values was enough to decide on the consistency test of the fuzzy decision matrix. The consistency ratio is an average derived from 3 decision matrices, which are made by lower, middle and upper values respectively. Hence the fuzzy eigen value (made up with 3 values) related to the fuzzy comparison matrix was obtained and yielded to consistency. In this case, the average value was close to CR = 0.005 (0.5%); it was concluded that the fuzzy matrix presented in Table 4 was consistent. This could suggest that different knowledge areas were distributed credits consistently at 99.5% level. The FAHP1 could be used as a process of validating the level of uncertainty, fuzziness, vagueness introduced in the judgments of the decision team (from ECSA) about the credit allocation exercise.

Determination of criteria fuzzy weights

The fuzzy weights were calculated using the geometric means of triangular elements from the fuzzy judgment matrix as shown in Table 5. The first line in this table that is associated with the unnormalized fuzzy weights, regarding mathematical sciences were computed as follows.

$$Y_l = (1 \times 1 \times \frac{1}{6} \times \frac{1}{6} \times 1 \times \frac{1}{8})^{\frac{1}{6}} = 0.390$$

$$Y_m = (1 \times 1 \times \frac{1}{5} \times \frac{1}{5} \times 1 \times \frac{1}{7})^{\frac{1}{6}} = 0.423$$

$$Y_u = (1 \times 1 \times \frac{1}{4} \times \frac{1}{4} \times 1 \times \frac{1}{6})^{\frac{1}{6}} = 0.467$$

The rest of fuzzy weights in Table 5 were calculated in the same way as shown above.
The centre of area (COA) method was used to derive the weights of criteria as shown in Table 6.

Table 5. Unnormalized fuzzy weights

	Yl	Ym	Yu
T	0.389	0.423	0.467
S	0.389	0.423	0.467
W	1.587	1.992	2.039
X	1.587	1.992	2.039
Y	0.389	0.423	0.467
Z	1.818	3.333	2.696
Sum	6.161	8.586	8.177
1/Sum	0.162	0.116	0.122

Table 6. Weight criteria derived from Centre of Area (COA)

Criterion	Weight
T	0.246
S	0.057
W	0.246
X	0.057
Y	0.057
Z	0.338

In its last column, Table 6 showed the deffuzified weights. The results showed that 33.8 % as the highest level of preference for credits (for relocation) among criteria. This reallocation is very important during curriculum design of the engineering qualification, i.e. Advanced Certificate. The credit for relocation gives a certain degree of freedom to universities to redistribute credits among knowledge areas. This is done with attention paid to the graduate attributes of the qualification such that the qualification displays some relevance to the industry by responding to the challenges of the societal community. An engineering curriculum should cover problem solving skills to as required by the profession [10], which pertain to engineering sciences and design aspects of the qualification. These knowledge areas come after credits for relocation. Hence, in terms of credit weights, the FAHP1 ranking is as follows: Z, (T, W), and (X, S, Y) as per credit strength proposed by ECSA. Nonetheless, the weights obtained from FAHP1 should be used to validate the ECSA weights.

Validity of criteria

The difference between the ECSA knowledge area weights and FAHP1 was very small as displayed in Table 7. Hence, one could conclude confidently that these two approaches gave very comparable results as the margin differences between the 2 approaches were indeed very small.

Table 7. Comparison between ECSA and FAHP1 weights.

Criterion	FAHP1 weight	ECSA weights	Absolute difference (AD)	% AD
T	0.246	0.25	0.004	0.4
S	0.057	0.05	0.007	0.7
W	0.246	0.25	0.004	0.4
X	0.057	0.05	0.007	0.7
Y	0.057	0.05	0.007	0.7
Z	0.338	0.35	0.012	1.2

Therefore, the existing knowledge areas credits associated with ECSA could be validated by the FAHP.

5. CONCLUSIONS

The versatility of FAHP tool has been found as a powerful tool to rank the knowledge areas of the Advanced Certificate in Engineering course, as taught in South African institutions of higher learning. This ranking was carried out consistently for the existing credit allocation as suggested by ECSA. Hence, FAHP has shown to validate the credit allocation by ECSA. Engineering qualification designers like ECSA's decision making group in designing a qualification could use the approach developed in this study for the allocation of credits to the knowledge areas. Universities of technologies and comprehensive universities could use FAHP approach to further develop, design and implement engineering courses. Even if after the implementation of the Advanced Certificate, FAHP could still be considered as a validation tool in the credit allocation process. Strength ratio approach between knowledge area credits to derive the pairwise comparisons was simple and elegant in the establishment of consistency in the judgments of experts. It is also suggested that the approach developed in this research could be applicable to other engineering qualifications.

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