Information System for the valuation of Universities in Spain

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Abstract— *The Spanish National Agency for Quality Assessment and Accreditation as part of its evaluation activities has established a procedure for evaluating both teaching and institutions, by means of the Institutional Assessment Programme. In this communication we shall focus on the external assessment phase for qualifications in the field of Industrial Engineering and specifically on the structures of the database for a Decision Support System on the universities' rankings. In particular, this paper will focus on obtaining the weight of the criteria and definition of the linguistic labels used in the external assessment phase.*

Keywords— Analytical Hierarchy Process (AHP), Linguistic Labels, Qualification evaluation, Weighting Criteria

1 Introduction

The university rankings which just 20 years ago were an innovation are today a normal characteristic in the majority of countries with extensive systems of higher education [7, 13, 16, 17, 18]. These lists have an increasing impact not only between the universities themselves, but also between different social sectors.

University rankings are lists of certain groups of institutions, classified in comparative form, and according to a common set of indicators, in descending order.

Likewise, the reorganisation at European scale of university studies as a result of the Bologna Process, will contribute in an active way to the harmonisation of basic European academic aspects. This aspect will allow, on the one hand, for a better connection between universities and on another hand, for an easier comparison between them; for which certain indicators of functioning will be necessary.

All the above leads us to think about the need for the existence of global rankings of universities as an instrument to measure their quality rigorously [7, 16]. In this context, the Decision Support Systems (DSS), seem to be useful for the evaluation of the qualifications in the universities' ranking.

In this paper, we shall focus on the area of industrial engineering within the Spanish university system and on the structure of the Database as a fundamental element of the DSS.

The aim of the paper is the use of the fuzzy AHP process to obtain the weight of the criteria within a DSS in order to facilitate the process of evaluation on the universities' rankings.

Another aim is to obtain the fuzzy numbers associated with the linguistic labels used to evaluate the ANECA in the external assessment phase.

The paper is organised as follows: The next section introduces the ANECA process. Section 3 introduces the linguistic variables and fuzzy sets. In section 4, the framework for the AHP method is defined. Section 5 describes the database. Section 6 shows the aggregation results and finally we outline the most important conclusions.

2 The ANECA Process

In this sense and within the framework of the Institutional Assessment Programme (*Programa de Evaluación Institucional*, "PEI"), the Spanish National Agency for Quality Assessment and Accreditation (*Agencia Nacional de Evaluación de la Calidad y Acreditación* "ANECA") presents this Guide [2] with the purpose of showing the steps in the Process of Institutional Assessment

The primary objective of the Institutional Assessment Programme is to facilitate an assessment process to officially improve the quality of education leading to obtain university degrees throughout the national territory, through self-diagnosis and the external view brought by experts.

The development of this programme is intended to promote assessment processes favouring the establishment or continuity of processes guaranteeing quality in teaching, as well as providing information to the students and their families, to society, to the governing bodies of the universities and to public administrations, regarding the quality of university teaching and their action plans.

This process is organised in three phases, see figure 1:

- *Self-assessment:* the "Self-assessment Report" describes and evaluates the situation of the assessed degree with respect to the criteria established, identifying strengths and weaknesses and enhancement proposals forming the basis of execution of the action plans that must be initiated on conclusion of the entire process. The report is written by the Self-assessment Committee.

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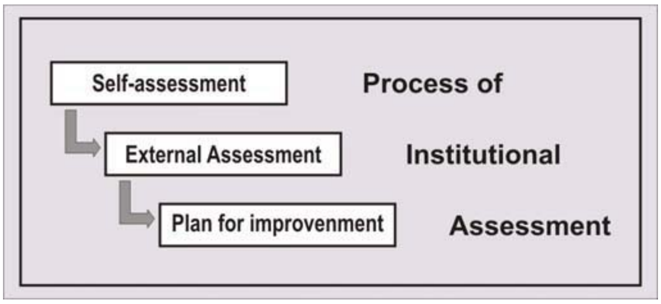

Figure 1: Phases of the Institutional Assessment Programme

- *External Assessment:* a group of external assessors to the teaching institution assessed, appointed by ANECA, and under its guidelines and supervision, analyzes the Self-Assessment Report, both through the study of documents and by means of a visit to the unit assessed, issues its recommendations, and proposes improvements. The result of this phase is the "External Assessment Report."

- *Plan for improvement*: it collects the main results of the Assessment process. This phase concludes with the plan for improvements of the degree, describing the proposed improvement actions in the Self-assessment and External Assessment phases, once their viability is analyzed. The tasks to be performed are determined according to their accomplishment, the persons responsible, resources involved, deadlines for their implementation, the indicators monitoring the actions proposed, and the benefits expected from them.

3 Linguistic variable and fuzzy sets

3.1 Linguistic variable

Most of the times, the decision-maker is not able to define the importance of the criteria or the goodness of the alternatives with respect to each criterion in a strict way. In many situations, we use measures or quantities which are not exact but approximate.

Since Zadeh [19] introduced the concept of fuzzy set and subsequently went on to extend the notion via the concept of linguistic variables, the popularity and use of fuzzy sets has been extraordinary. We are particularly interested in the role of linguistic variables as an ordinal scale and their associated terms, in this case triangular fuzzy number, as used in the multi-criteria decision making.

By a *linguistic variable,* [20,21,22], we mean a variable whose values are words or sentences in a natural or artificial language. For example *Age* is a linguistic variable if its values are linguistic rather than numerical, i.e., *young, not young, very young, quite young, old, not very old and not very young*, etc., rather than numbers as 20, 21,22, 23,.... .

Definition.1- A linguistic variable is characterized by a quintuple

$$\{X; T(X); U; G; M\}$$

in which

1. X is the name of the variable,
2. $T(X)$ is the term set of X, that is, the collection of its linguistic values
3. U is a universe of discourse,
4. G is a syntactic rule for generating the elements of $T(X)$ and
5. M is a semantic rule for associating meaning with the linguistic values of X.

In general for the decision-maker it is easier when he/she evaluates their judgments by means of linguistic terms. In those cases, the concept of fuzzy number is more adequate than that of real number.

3.2 Fuzzy sets

Then we have identified the linguistic variable with a fuzzy set [3,10,11]. The fuzzy set theory, introduced by Zadeh [19] to deal with vague, imprecise and uncertain problems has been used as a modelling tool for complex systems that can be controlled by humans but are hard to define precisely. A collection of objects (universe of discourse) X has a fuzzy set A described by a membership function f_A with values in the interval $[0,1]$.

$$f_A : X \to [0,1]$$

Thus A can be represented as $A = \{f_A(x) \mid x \in X\}$. The degree that u belongs to A is the membership function $f_A(x)$.

The basic theory of the triangular fuzzy number is described in Klir [12].

With regard to the fuzzy numbers, we will show only the mathematical operations that will be used throughout the development of the paper.

Definition 2. If T_1 and T_2 are two triangular fuzzy numbers defined by the triplets (a_1, b_1, c_1) and (a_2, b_2, c_2), respectively. Then, for this case, the necessary arithmetic operations with positive fuzzy numbers are:

a) Addition

$$T_1 \oplus T_2 = [a_1 + a_2, b_1 + b_2, c_1 + c_2] \quad (1)$$

b) Subtraction

$T_1 \Theta T_2 = T_1 + (-T_2)$ when the opposite $-T_2 = (-c_2, -b_2, -a_2)$

$$\text{then} \quad T_1 \Theta T_2 = [a_1 - c_2, b_1 - b_2, c_1 - a_2] \quad (2)$$

c) Multiplication

$$T_1 \otimes T_2 = [a_1 \times a_2, b_1 \times b_2, c_1 \times c_2] \quad (3)$$

d) Division

$$T_1 \varnothing T_2 = \left[[a_1, b_1, c_1] \cdot [1/c_2, 1/b_2, 1/a_2]\right], \quad 0 \neq [a_2, b_2, c_2] \quad (4)$$

e) Scalar Multiplication

$$k \circ T_1 = (k \circ a_1, k \circ b_1, k \circ c_1) \quad (5)$$

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4 The Analytic Hierarchy Process Method (AHP)

The Analytic Hierarchy Process (AHP methodology [14,15] has been accepted by the international scientific community as a robust and flexible multi-criteria decision making tool for dealing with complex decision problems. AHP has been applied to numerous decision problems such as energy policy [1,7], project selection [6], measuring business performance [1], and evaluation of advanced manufacturing technology [4,5].

- Basically, AHP has three underlying concepts: Structuring the complex decision problem as a hierarchy of goal, criteria and alternatives,
- Pair-wise comparison of elements at each level of the hierarchy with respect to each criterion on the preceding level,
- and finally vertically synthesizing the judgements over the different levels of the hierarchy.

AHP attempts to estimate the impact of each one of the alternatives on the overall objective of the hierarchy. In this case, we only apply the method in order to obtain the criteria's weights.

We assume that the quantified judgements provided by the decision-maker on pairs of criteria *(C_i, C_j)* are represented in an *nxn* matrix as in the following:

$$C = \begin{array}{c} \\ C_1 \\ C_2 \\ . \\ . \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix} \end{array}$$

(6)

The c_{12} value is supposed to be an approximation of the relative importance of C_1 to C_2, i.e., $c_{12} \approx (w_1/w_2)$. This can be generalized and the statements below can be concluded:

1. $c_{ij} \approx (w_i/w_j)$ $i,j=1, 2, \ldots, n$
2. $c_{ii}=1$, $i=1,2,\ldots,n$
3. If $c_{ij}=\alpha$, $\alpha \neq 0$, then $c_{ji}=1/\alpha$, $i=1,2,\ldots,n$
4. If C_i is more important than C_j then $c_{ij} \cong (w_i/w_j)>1$

This implies that matrix *A* should be a positive and reciprocal matrix with 1's in the main diagonal and hence the decision-maker needs only to provide value judgements in the upper triangle of the matrix. The values assigned to c_{ij} according to Saaty scale are usually in the interval of 1-9 or their reciprocals.

It can be shown that the number of judgements (*L*) needed in the upper triangle of the matrix are:

$$L = n(n-1)/2 \qquad (7)$$

where *n* is the size of the matrix *C*.

The matrixes associated to the AHP approach are reciprocal, thus:

- The maximum eigenvalue ($\lambda_{\max}$) is a positive real number and such that $\lambda_{\max} \geq$ n.
- Associated with this eigenvalue is a vector whose components are also positive. If this vector is normalized the vector of weights associated with the matrix is obtained.

Where the values are fuzzy, not crisp; instead of using lambda as an estimator to the weight, we will use the geometric normalized average, expressed by the following expression:

$$w_i = \frac{\prod_{j=1}^{n}\left(a_{ij}, b_{ij}, c_{ij}\right)}{\sum_{i=1}^{m}\prod_{j=1}^{n}\left(a_{ij}, b_{ij}, c_{ij}\right)} \qquad (8)$$

where, $\left(a_{ij}, b_{ij}, c_{ij}\right)$ is a fuzzy number.

5 The database

The Database has two parts. The first part consists of the summary of the different Reports of External Evaluation, published by ANECA. These reports are given by the members of the External Assessment Committee who are persons qualified by ANECA; the valuation given by the external assessors is impartial.

The second part of the database, which is the focus of this paper, corresponds with obtaining the weights of the criteria, as well as the numerical representation of the labels. See Figure 2.

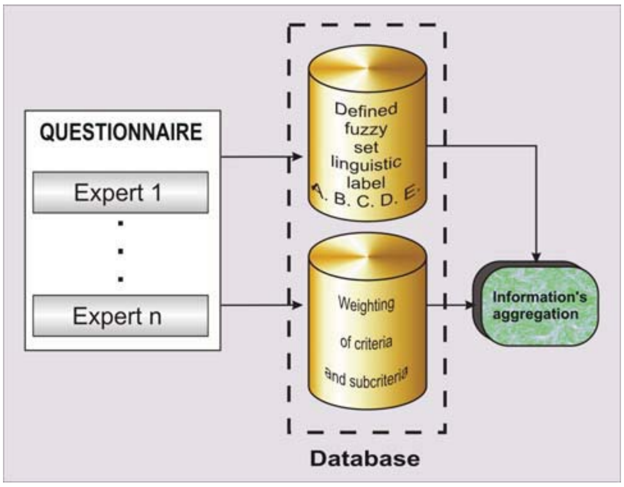

Figure 2: The database corresponding to this part of the work.

The study carried out has been based on a questionnaire designed to such effect. ANECA itself sent the questionnaire to the experts that it determined as proper assessors. The questionnaire was sent / answered by e-mail.

This questionnaire consists of two clearly differentiated parts;

- The first one has been produced on the basis of the hierarchic structure of the criteria and subcriteria (Table 1), using the AHP methodology to do so.
- The second part refers to the linguistic labels used in the ANECA survey for the external evaluation of university qualifications.

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Table 1. Weighting criteria/subcriteria

CRITERIA			General Weighting		
1st LEVEL	2nd LEVEL	3rd LEVEL	3th. LEVEL	2nd LEVEL	1st LEVEL
1. Educational programme (E.P)	1.1. Aims of the programme	Aims of the E.P.	(3.39,**5.26**,8.01)		
		Admission profile	(3.39,**5.26**,8.01)	(6.77,**10.52**,16.02)	
	1.2. Studies plan and its structure	Curricular content	(1.50,**2.32**,3.54)		
		Curricular coherence	(1.50,**2.32**,3.54)		
		Curricular consistency	(1.50,**2.32**,3.54)		
		Curricular updating	(1.50,**2.32**,3.54)		
		Aims of E.P.	(1.50,**2.32**,3.54)	(7.49,**11.61**,17.72)	(16.61,**22.13**,29.14)
2. Organization of teaching	2.1. Management and planning	Planning	(5.27,**7.94**,11.81)	(5.27,**7.94**,11.81)	
	2.2. Management and organization	Communication	(1.59,**2.39**,3.57)		
		Organisation of teaching	(1.59,**2.39**,3.57)		
		Improvement processes	(1.59,**2.39**,3.57)	(4.78,**7.16**,10.70)	(11.33,**15.10**,20.04)
3. Human Resources	3.1. Academic staff (AS)	Appropriateness AS	(5.11,**7.95**,12.15)		
		Implication AS	(5.11,**7.95**,12.15)	(10.21,**15.90**,24.29)	
	3.2. Administration and service staff (ASS)	Adaptation ASS	(2.50,**3.79**,5.94)	(2.50,**3.79**,5.94)	(14.44,**19.70**,26.70)
4. Material Resources	4.1 Classrooms	Appropriateness for numbers of students	(1.58,**2.50**,3.94)	(1.58,**2.50**,3.94)	
	4.2 Work Spaces	Appropriateness for numbers of students	(0.51,**0.81**,1.31)		
		Appropriateness (AS and ASS)	(0.51,**0.81**,1.31)		
		Infrastructures: practical	(0.51,**0.81**,1.31)	(1.53,**2.44**,3.93)	
	4.3. Laboratories, workshops and experimental spaces	Appropriateness for number of students	(1.82,**2.86**,4.53)	(1.82,**2.86**,4.53)	
	4.4. Library and document banks	Correctly furnished	(0.69,**1.09**,1.78)		
		Quality, quantity, …	(0.69,**1.09**,1.78)	(1.38,**2.19**,3.56)	(7.55,**9.99**,13.46)
5. Training Process	5.1. Student assistance and integral training	Capture	(0.54,**0.84**,1.33)		
		Student welcome actions	(0.54,**0.84**,1.33)		
		Support programmes	(0.54,**0.84**,1.33)		
		Professional orientation programmes	(0.54,**0.84**,1.33)		
		Tutorial action programmes	(0.54,**0.84**,1.33)		
		Integral training	(0.54,**0.84**,1.33)	(3.24,**5.06**,8.01)	
	5.2. Teaching-learning process	Methodology	(1.55,**2.46**,3.84)		
		Evaluation	(1.55,**2.46**,3.84)		
		External practical	(1.55,**2.46**,3.84)		
		Mobility	(1.55,**2.46**,3.84)	(6.21,**9.84**,15.34)	(11.04,**14.90**,20.10)
6. Results	6.1. Results of educational programme	Effectiveness of E.P.	(1.56,**2.73**,4.67)		
		Student satisfaction	(1.56,**2.73**,4.67)	(3.13,**5.47**,9.35)	
	6.2. Graduate results	Compliance with the graduate profiles	(3.39,**5.99**,10.34)	(3.39,**5.99**,10.34)	
	6.3. Academic staff results	Academic staff satisfaction	(1.82,**3.21**,5.70)	(1.82,**3.21**,5.70)	
	6.3. Results in society	Employers and other groups	(0.10,**1.76**,3.08)		
		Social link	(0.10,**1.76**,3.08)	(0.20,**3.52**,6.17)	(8.54,**18.18**,24.75)
Source: own production			**100.00**	**100.00**	**100.00**

Likewise, we will take into account the possible valuations of the experts, expressed in linguistic terms (A, B, C, D) These labels are arranged from largest to smallest as follows: A > B > C > D and with the semantics that we will see later.

It should be remembered that the results obtained correspond to a problem of group decision-making, formed by *n* experts, from whom we will obtain:

1.-The criteria weight as a result of the consensus

2.- The membership functions of the fuzzy numbers that represent the linguistic labels A,B,C and D.

5.1 *Obtaining the weightings of the criteria/subcriteria*

According to Table 1, the hierarchy structure has three levels. Considering expression (7), the large number of questions might lead to the survey not being answered, since L = 74, as we have 6 in 1^{st} level criteria, subcriteria 16 in 2^{nd} level and 37 in 3^{rd} level indicators. This results in a questionnaire which is not feasible for experts to answer.

For this, and since the influence of the third level on the weight of the previous ones is practically null, a uniform distribution on them was supposed.

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For the first and second level, the procedure is as follows: firstly, we ask if all the criteria/subcriteria have the same weight, if so, we pass to the following level.

On the contrary, if they do not have the same weight, it will be continued by the following question of the questionnaire.

In this part, there is a question that asking about the order of importance of the criteria/subcritera; and finally, using the linguistic labels defined by Saaty [14], the criteria/subcriteria are compared at the same level, taking into account the order established before.

We chose to ask only for one row of the pairwise matrix and from here to generate the rest of the information matrix, which was carried out completely consistently. Thus, this part of the questionnaire had only 21 questions.

5.2 *Obtaining the linguistic evaluations*

The second part of the questionnaire is based on the semiquantitative survey of the Evaluation of the Education inside the protocol to elaborate the Report of External Evaluation developed by ANECA, in which the following labels are used: A: Excellent, B: Good, C: Average, D: Deficient. For the valuation of these labels we use the interval [0, 10].

These linguistic variables, by the uncertainty of their nature, justified the use of fuzzy numbers associated with each linguistic term.

6 The results of the aggregation for the group decision experts

By means of a primary group decision-making process, it is possible to see the results of the weighting of the criteria and sub-criteria for all the experts (Table 1).

Table 2. Fuzzy numbers associated with the labels A,B,C and D.

Semi quantitative labels	General
A: Excellent	(8.1354, 9.4054, 10.0000)
B: Good	(5.8108, 7.1081, 8.4054)
C: Average	(3.5090, 4.8108, 6.1126)
D: Deficient	(0.7355, 2.5135, 4.2916)

Now, taking these weightings as the base; and the definition of semiquantitative labels (Table 2), obtained by ANECA's own experts, it is possible for us, attending to these six criteria, to order the different Universities. We make reference, in this case, only to the area of industrial engineering.

For the evaluation of the alternatives the methodology used has been the fuzzy weighted sum model as:

$$FWSM = \sum_{j=1}^{n} \tilde{w}_j \cdot \tilde{a}_{ij} \quad (9)$$

where, $\tilde{w}_j$ and $\tilde{a}_{ij}$ are fuzzy numbers.

The defuzzification method used is described in [8] when:

$$I_{\beta,\lambda}(A_i) = \beta S_M(A_i) + (1-\beta)\lambda S_R(A_i) + (1-\beta)(1-\lambda) S_L(A_i)$$

In this way, we have defined a fuzzy number as a function of the three integrals, $S_L(A_i)$, $S_M(A_i)$ and $S_R(A_i)$, where $S_R(A_i)$ represents the upper mean value associated with the inverse function of $f_A^R(x)$, $S_L(A_i)$ is the lower mean value of the $g_A^L(x)$ function and $S_M(A_i)$ is the area of the core of the fuzzy number, β ∈ [0,1] is the index of modality that represents the importance of the central value against the extreme values, and λ ∈ [0,1] is the degree of optimism of the decision maker.

We have considered the case in which the three areas have the same weight and it would correspond to the neutral decision maker, when $\alpha = 1/2$ y $\beta = 1/3$

Taking as an example (Table 3), the outcome results of the DSS, for the real case of the evaluation of five universities in the qualifications of industrial engineering, where we have obtained results both for the principal criteria and for the global evaluation.

Table 3: Ranking result for five Universities.

Criteria	C1 Educational Programme	C2 Teaching Organizatio	C3 Human Resources	C4 Material Resources	C5 Educational Process	C6 Results	IAP Gobal
U1	0.062	0.033	0.071	0.040	0.042	0.056	0.306
U2	0.100	0.067	0.106	0.049	0.055	0.089	0.466
U3	0.129	0.086	0.105	0.067	0.098	0.119	0.604
U4	0.118	0.080	0.088	0.038	0.075	0.081	0.482
U5	0.125	0.089	0.105	0.047	0.082	0.100	0.548

7 Conclusions

For the assessors/experts it is simpler to express their knowledge by means of linguistic labels, instead of having to do so by means of numerical values. For that reason, it is preferable to prepare a questionnaire to obtain the experts' knowledge, in which the answers are in the form of linguistic variables. These linguistic variables have been modelized by means of fuzzy triangular numbers and from a methodology widely accepted by the scientific community, since it is the Analytical Hierarchic Process; developed by Saaty in 1980.

Taking Table 1into account, we conclude that in general the most important criterion is the Educational Programme and that the lowest weighting is obtained for the Material Resources.

For future work, it would be interesting to carry out a study of the aggregation of the information as a secondary process. In this process the weight of the criteria and subcriteria are obtained for every expert. Later all this information would be aggregated.

Moreover, a comparative primary and secondary study of both types of processes would be desirable.

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Similarly, as future work, it would be interesting to make a comparative study of the evaluation criteria according to the area of the different experts. It is possible that the valuation of an expert from the area of engineering does not value the criteria in the same way as another from the humanities.

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