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A decision support system to develop a quality management in academic digital libraries

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ABSTRACT

Academic digital libraries are getting more benefit from the Web possibilities to help with teaching, learning and research activities. Because of it, more and more people use the services that they offer. Therefore, it is very important that the academic digital libraries provide a good service in order to satisfy the users' expectations. The aim of this paper is to present a decision support system assisting the staff of the academic digital libraries to make decisions in order to meet the users' needs and, in such a way, to increase the number of users utilizing them. To do so, the decision support system is composed of several decision rules which generate recommendations according to both objective and subjective criteria to improve the quality of the services offered by the academic digital libraries.

1. Introduction

The arrival of the World Wide Web has enabled the proliferation of new sources of content and information. In 2008, Web 2.0 technologies made possible user-contributed content to directly compete, in scale and popularity, with the traditional "content" industries such as newspapers, magazines, TV, video, books, and so on [1].

One of these new sources of information is the academic digital library [2,3], which plays an important role in bridging students, academicians and researchers' needs of information [4]. Whereas the library used to be an obvious first port of call when seeking information, several studies reveal that this is no longer the case. For instance, a study undertaken by the Pew Internet and American Life Project in 2007 found that almost 60% of respondents would consult the Internet, while just over 10% would consult the public library [1,5].

Academic digital libraries can integrate research resources and enable users to search for specific information in virtual space [6]. On the one hand, several sources of information as, for example, electronic bulletin boards, online databases, and local magnetic or optical databases, are available only in electronic form [7]. On the other hand, academic digital libraries can support intellectual and academic endeavors not only for information seeking but also for researching, exploring and growing their knowledge by adapting the information systems and human–computer–interaction technologies [4].

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As a result of the popularity of the academic digital libraries, there are many people whose expectations and demands are increasing for better quality and functionality of the services offered by the academic digital libraries. Consequently, a major challenge faced by academic institutions is how to measure the performance of their digital libraries in the context of users' perspectives and how far their digital libraries satisfy the users' needs.

Measures related to richness of resources have tended to be used to evaluate the quality of academic digital libraries. Traditional measures such as the number of journal subscriptions, number of volumes owned, size of budget, number of patrons served, and so on, have been used in the quality evaluation of academic digital libraries [8]. However, measures based solely in terms of number of resources have become outdated. Since an academic digital library, and any other type of digital library as well, is designed to be used for people, its performance should be evaluated with a new approach considering users' needs. That is, the quality of academic digital libraries must be evaluated by their users.

Several quality evaluation methods of digital libraries based on users' perceptions have been proposed in the literature [9–11]. These methods provide the performance that the users perceive on the services offered by the academic digital libraries, but not give any advice or suggestion to improve them. However, it is important not only to obtain the quality level of the services offered by the academic digital library but also providing some recommendations in order to improve them and, in such a way, to fulfill the users' expectations. Academic digital libraries are designed to support users and if they do not meet the users' expectations, they fall into oblivion and terminate their operation [10].

The objective of this paper is to present a decision support system (DSS) to develop a quality management in academic digital libraries. It supports the staff to make decisions with the aim of improving the quality of the services offered by the academic digital library. To do so, the DSS takes into account several subjective criteria which are related to users' judgments. However, although it is essential to consider the users' opinions in the quality evaluation of academic digital libraries, it does not mean that all traditional quantitative criteria have to be excluded. Hence, the DSS also incorporates some objective criteria which are related to the quantitative data of the academic digital library. According to the subjective and objective criteria, the DSS provides some recommendations to improve the service and functionality of the services provided by the academic digital libraries in order to increase the number of users accessing to the academic digital library and the number of queries that they execute. The DSS is based on a set of decision rules that are activated depending on the values of the objective and subjective criteria. The values of the objective criteria are obtained from the data supplied by the academic digital library, whereas to obtain the values of the subjective criteria, an approach following the quality evaluation model based on fuzzy linguistic information presented in [12] along with the LibQUAL+ methodology [13,14] is used. The main innovation of the paper is to present the first DSS to develop a quality management in academic digital libraries which incorporates quality qualitative and quantitative criteria and recommendation rules to help the staff to make decisions.

The paper is set out as follows. In Section 2, we introduce the theoretical bases of our DSS, i.e., the fuzzy linguistic approach for computing with words and the LibQUAL+ methodology. Section 3 describes the DSS proposed in this contribution. To illustrate the application of this DSS, three Spanish academic digital libraries are evaluated in Section 4. Finally, we offer some concluding remarks and future work in Section 5.

2. Preliminaries

The theoretical bases of the DSS rely on the tools outlined in this section. Firstly, we introduce the ordinal fuzzy linguistic approach for computing with words. Secondly, we describe the LibQUAL+ methodology.

2.1. A fuzzy linguistic approach for computing with words

There exist many problems where the information cannot be assessed precisely in a quantitative form but it may be done in a qualitative one, and therefore the use of a linguistic approach is necessary [15].

The fuzzy linguistic approach is a suitable technique to deal with fuzzy and qualitative aspects of problems. Here, the information is modeled by means of linguistic terms supported by linguistic variables [16–18], which are defined via a syntactic rule and a semantic rule, and whose values are not numbers but sentences or words in a natural language.

The fuzzy linguistic approach is less precise than the numerical one, but it presents the following advantages: (i) the linguistic description is with ease understood by human beings even when the context is changing or the concepts are abstract, and (ii) it decreases the effects of noise since, as it is known, the more refined the assessment scale is, the more sensitive to noise it becomes (linguistic scales are less refined than numerical scales and consequently they are less sensitive to error apparition and propagation).

Among the different linguistic approaches existing in the literature [15], the ordinal fuzzy linguistic approach is very useful because it facilitates the fuzzy linguistic modeling very much as it simplifies the definition of the semantic and syntactic rules.

The ordinal fuzzy linguistic approach [19,20] is defined by considering a finite and totally ordered linguistic term set $S = \{s_i\}$, $i \in \{0, \ldots, g\}$, where $s_i < s_j$ holds if and only if $i < j$. Usually, the set is composed of an odd number of linguistic terms, seven or nine, representing the mid-term an assessment of "approximately 0.5" and the rest of the linguistic terms being situated symmetrically around it. The semantics of the linguistic terms is established from the ordered structure of the set by considering that each linguistic term for the pair (s_i, s_{g-i}) is equally informative. As example, a set composed of nine linguistic terms could be as follows: $S = \{s_0 = \text{None}, s_1 = \text{Extremely Low}, s_2 = \text{Very Low}, s_3 = \text{Low}, s_4 = \text{Medium}, s_5 = \text{High}, s_6 = \text{Very High}, s_7 = \text{Extremely High}, s_8 = \text{Total}\}$.

An advantage of the ordinal fuzzy linguistic approach is the simplicity and efficiency of its computational model for computing with words. It is based on the symbolic computation [19,20], acting by direct computation on linguistic terms by considering the order of such linguistic terms in the ordered structure. This symbolic tool seems natural when using the fuzzy linguistic approach because the linguistic terms are simply approximations which are given and handled when it is impossible or unnecessary to obtain more accurate values.

The ordinal fuzzy linguistic approach for computing with words is defined by establishing the *negation*, *conjunction* and *disjunction* operators for the linguistic model, and different aggregation operators, e.g., weighted norms, uninorms or ordinal mean type operators [21]. The *negation* operator is defined as $\mathrm{Neg}(s_i) = s_j$, where $j = g - i$, and the *conjunction* and *disjunction* operators are defined respectively such that s_i AND $s_j = \mathrm{MIN}(s_i, s_j)$, and s_i OR $s_j = \mathrm{MAX}(s_i, s_j)$. In this way, $\mathrm{MIN}(s_i, s_j) = s_i$ if $s_i < s_j$, and $\mathrm{MAX}(s_i, s_j) = s_i$ if $s_i > s_j$.

Besides the above operators, the DSS uses tools of computing with words based on the Linguistic Ordered Weighted Averaging (LOWA) operator [20] to compute the quality assessment provided by the users. The LOWA operator is an important aggregation operator of ordinal linguistic values based on the Ordered Weighted Averaging (OWA) operator defined by Yager [22]. It is used to aggregate non-weighted ordinal fuzzy linguistic information, that is, linguistic information values with equal importance.

Definition 1. Let $A = \{a_1, \ldots, a_m\}$ be a set of linguistic terms to be aggregated, then the LOWA operator, ϕ, is defined as:

$$\begin{aligned}\phi(a_1, \ldots, a_m) &= W \cdot B^T \\ &= C^m\{w_k, b_k, k = 1, \ldots, m\} = \\ &= w_1 \odot b_1 \oplus (1 - w_1) \odot C^{m-1}\{\beta_h, b_h, h = 2, \ldots, m\}\end{aligned} \tag{1}$$

where $W = [w_1, \ldots, w_m]$ is a weighting vector, such that, $w_i \in [0, 1]$ and $\Sigma_i w_i = 1$. $\beta_h = \frac{w_h}{\Sigma_2^m w_k}$, and $B = \{b_1, \ldots, b_m\}$ is a vector associated to A, such that, $B = \sigma(A) = \{a_{\sigma(1)}, \ldots, a_{\sigma(m)}\}$, where $a_{\sigma(j)} \leq a_{\sigma(i)}\ \forall i \leq j$, with σ being a permutation over the set of linguistic terms A. C^m is the convex combination operator of m labels. If $m = 2$, then it is defined as:

$$C^2\{w_i, b_i,\ i = 1, 2\} = w_1 \odot s_j \oplus (1 - w_1) \odot s_i = s_k \tag{2}$$

such that, $k = \min\{g, i + round\big(w_1 \cdot (j - i)\big)\}$, $s_j, s_i \in S$, $(j \geq i)$, where *"round"* is the usual round operation, and $b_1 = s_j$, $b_2 = s_i$. If $w_j = 1$ and $w_i = 0$, with $i \neq j\ \forall i$, then the convex combination is defined as: $C^m\{w_i, b_i, i = 1, \ldots, m\} = b_j$.

The LOWA operator is an "or–and" operator [20] and its behavior can be controlled by means of W. In order to classify OWA operators with regards to their localization between "or" and "and", Yager [22] introduced a measure of *orness*, associated with any vector W: $orness(W) = \frac{1}{m-1}\sum_{i=1}^{m}(m - i)w_i$. This measure characterizes the degree to which the aggregation is like an "or" (MAX) operation. Note that an OWA operator with $orness(W) \geq 0.5$ will be an *orlike*, and with $orness(W) < 0.5$ will be an *andlike* operator.

An important question of the LOWA operator is the determination of the weighting vector W. In [22], it was defined an expression to obtain W that allows to represent the concept of fuzzy majority [23] by means of a fuzzy linguistic non-decreasing quantifier Q [24]:

$$w_i = Q\left(\frac{i}{m}\right) - Q\left(\frac{i-1}{m}\right),\ i = 1, \ldots, m \tag{3}$$

The membership function of Q is given by Eq. (4), with $a, b, r \in [0, 1]$. Some examples of non-decreasing proportional fuzzy linguistic quantifiers are: "most" (0.3, 0.8), "at least half" (0, 0.5), and "as many as possible" (0.5, 1).

$$Q(r) = \begin{cases} 0 & \text{if } r < a \\ \dfrac{r-a}{b-a} & \text{if } a \leq r \leq b \\ 1 & \text{if } r > a \end{cases} \tag{4}$$

When a fuzzy linguistic quantifier Q is used to compute the weights of LOWA operator ϕ, it is symbolized by ϕ_Q.

As the information provided by the humans is inherently non-numeric, partial evaluations, preferences, judgments, and weights are usually expressed linguistically. The use of words or sentences rather than numbers is, in general, less specific, more flexible, direct, realistic, and adequate form to express the qualitative aspects of the problem at hand [15]. That is, as the natural language is the standard representation of those concepts that humans use for communication [25], it seems natural that they use words (linguistic terms) instead of numerical values to provide their opinions. For this reason, we assume a fuzzy linguistic approach to represent the users' judgments on the subjective criteria.

2.2. LibQUAL+ methodology

To improve the quality evaluation model presented in [12] and to obtain a better quality management in academic digital libraries, the LibQUAL+ methodology [13,14] may be used.

In 1999, a major project to develop a standardized measure of library service quality was undertaken by the Association of Research Libraries in collaboration with the Texas A&M University. The result of this project is LibQUAL+ [13,14], which is an

extension of the SERVQUAL (for SERVice QUALity) tool. SERVQUAL has been carefully tested and widely accepted after a dozen years of application in the private sector and elsewhere. From its grounding in the private sector, the SERVQUAL instrument brings a particular theoretical perspective: only customers judge quality; all other judgments are essentially irrelevant. In the same way, LibQUAL+ focuses on user perception to measure library service quality and it can be considered as one of the most prominent successes in the field of library and information management [26].

LibQUAL+ has emerged as both a process and a tool that enables institutions to address service quality gaps between their expectations and the perceived service delivery, to enhance student and faculty research, teaching, and learning needs. The main LibQUAL+ research instrument is a survey that consists of 22 core items. For each item, the user rates on a 9-point Likert scale: (i) the minimum acceptable level of service, (ii) the level of service the user personally desires, and (iii) the level of service the user believes libraries currently provide.

For each question, gap scores are obtained between desired and perceived expectations and between minimum and perceived expectations. The zone of tolerance is the difference between the minimum and desired scores. Optimally, perceived performance assessments should fall comfortably within that zone. A positive gap means that the service performance has surpassed customers' expectations, whereas a negative gap indicates that the service performance has fallen short of the expected service. Gap models are by instinct attractive to many research consumers [14] since its interpretation is straightforward. As an example, if the perceived rating on an item is below the minimum, it obviously means that the item evaluated needs improvement. On the other hand, if the perceived rating on an item is very above the desired level of service, it may imply that the item is not a concern to consumers.

3. A DSS for developing a quality management in academic digital libraries

In this section we present the DSS generating recommendations to the staff of the academic digital libraries with the aim of improving the services offered by the academic digital libraries. It presents the following characteristics:

- It is user-oriented as the user participation in the quality evaluation process of services is fundamental to correctly draw the situation of the service.
- It uses both objective criteria, related to the quantitative data of the academic digital library, and subjective criteria, related to the users' judgments, to evaluate the quality of the services provided by the academic digital libraries and to generate recommendations according to them.
- The aim of these recommendations is to satisfy the users' expectations on the services offered by the academic digital libraries and, in such a way, to increase the number of users utilizing them.

In the following, we describe both the objective and the subjective criteria which are used by the DSS and show the decision rules which are applied to generate the recommendations.

3.1. Objective criteria

To establish the objective criteria, that will be considered by the DSS, it is convenient to analyze the activity of an academic digital library from the perspective of the General Systems Theory [27], which was originally proposed by Bertalanffy, using one of the classic graphics that represent an information system. According to Bertalanffy, the General System Theory is based on the attempt to build mathematical models in such a way that once developed they can be utilized by different disciplines. In this regard we follow authors like Ingwersen [28] or Thelwall [29], which attempt to generate a mathematical basis to validate the assessments that they pose. This mathematical support will be the basis to formulate and establish models.

The interpretation of the graph in which the activity of a library is shown as an information system would be as follows: from several system inputs, usually measured as economic investments in the different facets of the library, various library processes generating resources and assets in the library entity are performed. These resources and assets begin several system outputs which are related to the services offered to the university community, that is, with the library–user interaction. Additionally, those benefits that are generated to the non-university community could also be included in the system outputs.

In the case of academic digital libraries, the system inputs, the library processes and the system outputs could be measured as follows:

- System inputs:
  - Amount of money per user.
  - Amount of money spent on e-resource per capita.
  - Amount of money spent on computer equipment per capita.
- Library processes:
  - Megabytes per capita.
  - Journal per researcher.
  - Journal per user.
  - Computers, which are used to check only and exclusively the collection of the academic digital library, per capita.
  - Computers, without Internet connection, per capita.
  - Digitalization of the library collection.

- System outputs:
  - Number of e-resources downloaded.
  - Papers downloaded per researcher.
  - Papers downloaded per user.
  - Queries on journals per researcher.
  - Accesses to the academic digital library per capita.
  - Queries on the library collection per capita.
  - Queries-searches on the academic digital library per researcher.
  - Queries-searches on the academic digital library per user.
  - Percentage of external accesses to the academic digital library.

Among the quantitative indicators of the system inputs, library processes and system outputs, we have selected four of them to be included in the DSS as they are the most related to the circulation of the users through the academic digital library. That is, the greater the circulation of the users through the academic digital library, the greater the number of users accessing to the academic digital library and the number of queries that they execute. The objective criteria considered are the following:

1. *Accesses to the academic digital library per capita* (oc_1). This objective criterion is defined as the total number of accesses to the academic digital library divided by the total number of academic members (students, teachers, staff of the digital library, and so on).
2. *Access points to the academic digital library per capita* (oc_2). This objective criterion is defined as the total number of public access points (computers, laptops, and so on) in the academic library to access to the digital library divided by the total number of users.
3. *Queries on the library collection per capita* (oc_3). This objective criterion is defined as the total number of queries on the collection of the academic digital library divided by the total number of academic members.
4. *Megabytes of the academic digital library per capita* (oc_4). The amount of information provided by a Website should be taken into account as a quality indicator. To measure this amount of information in a digital library, the total number of megabytes of the digital library is divided by the total number of users. This objective criterion is similar to the size of the collection per capita in the traditional libraries.

Finally, it is important to note that the values of the above quantitative indicators are directly obtained from the data provided by the academic digital libraries.

3.2. Subjective criteria

In [30], an information quality framework defined in the context of management information systems was presented. This framework defines four major quality dimensions: (i) *intrinsic quality*, which addresses the very nature of the information and whose main criterion is the accuracy of the information, (ii) *contextual quality*, which emphasizes the importance of the informative aspects of information but from a task perspective and highlights the requirement that information quality must be considered within the context of the task at hand, (iii) *representational quality*, which emphasizes the importance of the technical aspects of the (computer-based) structure of the information and requires information systems to present their information in such a way that it can be represented concisely and consistently, easy to understand and easy to manipulate, and (iv) *accessibility quality*, which emphasizes the importance of the technical aspects of computer systems that provided access to information and requires the information system to be accessible but secure. It also establishes that the quality of the information systems cannot be evaluated separately from the information consumers' opinions (people who use information).

This information quality framework has been satisfactorily applied to previous quality models for personal Websites [31] and mobile Internet services [32]. Furthermore, in [12], a quality evaluation model, using fuzzy linguistic information to represent the users' perceptions, of digital libraries was presented using this information quality framework. It defined an evaluation scheme of digital libraries contemplating the above four quality dimensions together with their digital quality criteria. As it was oriented to users because the user participation in the quality evaluation processes of services is fundamental to correctly draw the situation of the service, a low number of subjective criteria was defined, being them easily understandable by the users in order that they did not cause the rejection of the users.

According to the evaluation model proposed in [12], the DSS uses the following ten subjective criteria which were defined in that model:

1. *You find what you are looking for* (sc_1).
2. *Coverage about search topics* (sc_2).
3. *Information electronic services about new inputs* (sc_3).
4. *Variety of search tools* (sc_4).
5. *Navigability of the Website* (sc_5).
6. *Understandability of the Website* (sc_6).
7. *Added value information profits* (sc_7).
8. *Satisfaction degree with the computing infrastructure* (sc_8).

QUALITY EVALUATION QUESTIONNAIRE

1. What is the degree in which you usually find what you are looking for?
2. What is the coverage degree about search topics?
3. What is the degree of information electronic service about new inputs?
4. What is the degree of variety of search tools?
5. What is the navigability degree of the Website?
6. What is the understandability degree of the Website?
7. What is the degree of added value information profits?
8. What is your satisfaction degree with the computing infrastructure?
9. What is your satisfaction degree with the response time?
10. What is the degree of training received?

Fig. 1. Quality evaluation questionnaire.

9. *Satisfaction degree with the response time* (sc_9).
10. *Training received* (sc_{10}).

In addition, to adapt the quality evaluation model of digital libraries presented in [12] according to the LibQUAL+ methodology, users are asked for impressions about the above ten subjective criteria according to the minimum level of service that they would find acceptable, the desired service level they expect, and their perceived service level (Fig. 1). As a result, for each one of the users, $u_j \in \{u_1, \ldots, u_n\}$, and each subjective criterion $sc_k \in \{sc_1, \ldots, sc_{10}\}$, there is a tuple ($MSL_{jk}$, DSL_{jk}, PPL_{jk}) encoding the minimum service level, the desired service level, and the perceived performance level given by the user u_j on the subjective criterion sc_k, respectively.

To obtain the global quality assessment regarding each subjective criterion sc_k (MSL_k, DSL_k, PPL_k), the opinions expressed by the users are aggregated by means of the LOWA operator:

$$\begin{aligned} MSL_k &= \phi_Q(MSL_{1k}, \ldots, MSL_{nk}) \\ DSL_k &= \phi_Q(DSL_{1k}, \ldots, DSL_{nk}) \\ PPL_k &= \phi_Q(PPL_{1k}, \ldots, PPL_{nk}) \end{aligned} \tag{5}$$

where MSL_k, DSL_k and PPL_k are the linguistic measures representing the minimum service level, the desired service level and the perceived performance level, respectively, of the academic digital library with respect to the subjective criterion sc_k, according to the majority (represented by the fuzzy linguistic quantifier Q) of the linguistic evaluation opinions given by the users.

Finally, gap analysis is done for each subjective criterion following the LibQUAL+ methodology. According to the gap model, service quality is the gap between user's expectations and perceptions. When experiences exceed expectations, the quality of the service is high, and vice versa. Four gaps may be identified: (i) a positive adequacy gap, that appears when the perceived performance level exceeds the minimum service level that is accepted by the users and it indicates the extent to which the service surpasses the lowest possible level that users will admit, (ii) a negative adequacy gap, that occurs when the offered service is below the minimum service level which is accepted by the users, (iii) a positive superiority gap, which opens up when the perceived performance level exceeds the desired service level, and (iv) a negative superiority gap, which means that the perceived performance level does not reach the desired service level but exceeds the minimum service level accepted by the users.

Taking into account these considerations, two scores are defined to obtain the weaknesses and strengths of an academic digital library according to the users' judgments: (i) the service adequacy score, and (ii) the service superiority score. On the one hand, the service adequacy score is an indicator of the extent to which an academic digital library is meeting the minimum expectations of its users. Given a subjective criterion sc_k, if the perceived performance level is higher than the minimum service level, $PPL_k > MSL_k$, the service adequacy score is positive and it is symbolized as SA_k^+, whereas if the perceived performance level is lower than the minimum service level, $PPL_k < MSL_k$, the service adequacy score is negative and it is symbolized as SA_k^-. When this score is negative, it may be used by the staff of the academic digital library to identify areas needing improvement. On the other hand, if the perceived performance level is higher than the desired service level, $PPL_k > DSL_k$, the service superiority score is positive and it is symbolized as SS_k^+. It is an indicator of the extent to which an academic digital library is exceeding the desired expectations of its users and it can be used to identify services satisfied outstandingly by the academic digital library.

3.3. Decision rules to generate recommendations

In the following we are going to show the decision rules applied to generate the recommendations. It is important to note that these decision rules are activated from the values of the service adequacy score of the criteria considered by the DSS.

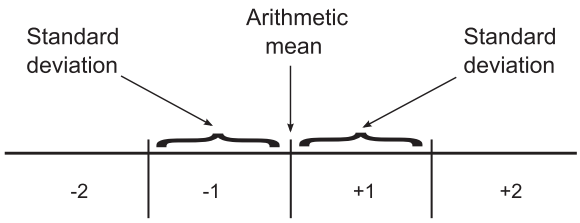

Fig. 2. Groups $(-2, -1, +1, +2)$.

3.3.1. Decision rules from the objective criteria

Here we describe the decision rules which are obtained from the objective criteria considered by the DSS. In such a way, first, we have to obtain the service adequacy score of the four objective criteria presented in Section 3.1. To do so, the following computations are carried out:

1. The arithmetic mean of each objective criterion among all the academic digital libraries which are being evaluated is computed. It establishes if the quality of an academic digital library on that objective criterion is better or worse than the average quality of the academic digital libraries on that objective criterion.
2. The standard deviation of each objective criterion among all the academic digital libraries which are being studied is computed. It may be used to distinguish among the academic digital libraries which are either too far (successfully as well as unsuccessfully) or too close to the average.
3. Once the arithmetic mean and the standard deviation have been obtained, the score of each academic digital library is situated in one of the four groups shown in Fig. 2.

The meaning of each one of these four groups is the following:

- -2: The evaluation on that objective criterion is much worse than the average. Therefore, it is urgent to improve it.
- -1: The evaluation on that objective criterion is worse than the average. It is important to improve that objective criterion but it is more important to make better the criteria which are in group -2.
- $+1$: The evaluation on that objective criterion is better than the average. Hence, it is conveniently satisfied.
- $+2$: The evaluation on that objective criterion is much better than the average. As a consequence, it is totally satisfied.

The group of each objective criterion is noted as $G(\cdot)$. For example, the group of the objective criterion oc_3 is $G(oc_3)$. Additionally, due to the high correlation between the objective criteria oc_1 and oc_3, we get a measure of the group which is composed of both criteria: $G(oc_{13}) = (G(oc_1) + G(oc_3))/2$. From the group in which each objective criterion is, the following decision rules are applied in order of importance.

- **Decision rule 1:** If $G(oc_{13}) < 0$, and $G(oc_2) < 0$, and $G(oc_4) < 0$, then the following recommendation is generated:
  - *The number of users accessing to the academic digital library is low and there are few access points in the academic digital library. Furthermore, the digital collection is poor. Maybe it causes the low number of users. It is advised to increase and to improve the digital collection.*
- **Decision rule 2:** If $G(oc_{13}) < 0$, and $G(oc_2) < 0$, and $G(oc_4) > 0$, then the following recommendation is generated:
  - *The number of users accessing to the academic digital library is low and there are few access points in the academic digital library, although the digital collection is appropriate. It is advised to increase the number of access points. In addition, it would be recommendable to give grants to the users for buying computers.*
- **Decision rule 3:** If $G(oc_{13}) < 0$, and $G(oc_2) > 0$, and $G(oc_4) > 0$, then the following recommendation is generated:
  - *There exist few accesses to the academic digital library, although the number of access points and the digital collection are appropriate. It is advised to train better to the users and to improve the query tools.*

The reason of this progressive scheme is that the academic digital libraries with a poor digital collection present few accesses and queries by the users. Likewise, an academic digital library with few access points will have few accesses and queries. However, it would be possible to find other different cases where the above decision rules cannot be satisfied. In these cases, the following decision rules are applied:

- **Decision rule 4:** If $G(oc_{13}) > 0$, and $G(oc_4) > 0$, and $G(oc_2) < 0$, then the following recommendation is generated:
  - *There exist few access points in the academic digital library. It is advised to increase the number of access points to query on the academic digital library and to give grants to the users for buying computers.*
- **Decision rule 5:** If $G(oc_{13}) > 0$, and $G(oc_2) > 0$, and $G(oc_4) < 0$, then the following recommendation is generated:
  - *Although the academic digital library has a good number of accesses and queries, the digital collection is poor. It is advised to increase and to improve the digital collection.*

Apart from generating recommendations, the DSS will show, when there exists an academic digital library whose evaluation on the objective criterion which has activated the decision rule is in the group $+2$, a message reporting the existence of that academic digital library with the aim of that the staff of the academic digital library may contact with the staff of the best

academic digital library on that criterion. In such a way, the DSS also increases the communication among the academic digital libraries in order to improve them.

3.3.2. Decision rules from the subjective criteria

Now we describe the decision rules which are obtained from the subjective criteria considered by the DSS.

According to the surveys filled by the users, different recommendations may be generated. To do so, from the service adequacy score of each subjective criterion and, in some cases, taking also into account the objective criteria to improve the recommendations, the following decision rules are applied:

- **Decision rule 6:** If SA_1^-, and $G(oc_4) < 0$, then the following recommendation is generated:
  - *It seems that users do not find out what they are looking for. Maybe it is due to that the digital collection is poor. It is advised to increase and to improve the digital collection.*
- **Decision rule 7:** If SA_1^-, and $G(oc_4) > 0$, then the following recommendation is generated:
  - *It seems that users do not find out what they are looking for. However, the digital collection is appropriate. It is advised to invest in training of users and to provide better query tools.*
- **Decision rule 8:** If SA_2^-, then the following recommendation is generated:
  - *Users think that the coverage of the academic digital library about search topics is poor. It is advised to increase the digital collection and to improve the mechanisms of information diffusion (mailing lists, news pages, etc.).*
- **Decision rule 9:** If SA_3^-, then the following recommendation is generated:
  - *Users are not well informed about new inputs in the academic digital library. It is advised to improve the mechanisms of information diffusion (mailing lists, news pages, etc.).*
- **Decision rule 10:** If SA_4^-, then the following recommendation is generated:
  - *Users think that the variety of search tools is not appropriate. It is advised to improve both the current search tools and the training of users.*
- **Decision rule 11:** If SA_5^-, or SA_6^-, then the following recommendation is generated:
  - *Users think that the navigability/understandability of the academic digital library Website is poor. It is advised to improve the Website design and to use more Web standards.*
- **Decision rule 12:** If SA_7^-, then the following recommendation is generated:
  - *Users think that the academic digital library should provide more added value information profits. It is advised to provide more added value information profits, as for example: completing the search results with links to other search engines and providing access to other Websites.*
- **Decision rule 13:** If SA_8^-, then the following recommendation is generated:
  - *Users think that the computing infrastructure of the academic digital library is not appropriate. It is advised to improve the computing infrastructure and to increase the number of access points.*
- **Decision rule 14:** If SA_9^-, then the following recommendation is generated:
  - *Users think that the response time of the academic digital library is not appropriate. It is advised to improve the system design and to invest in servers more powerful.*
- **Decision rule 15:** If SA_{10}^-, then the following recommendation is generated:
  - *Users do not receive training in the use of the academic digital library. It is advised to invest in the training of users.*

Finally, it is important to note that the DSS will report the academic digital libraries which satisfy outstandingly the subjective criterion in which the academic digital library evaluated has obtained a bad result. To do so, the service superiority score on each subjective criterion is used. If the service superiority score is positive (SS_k^+), it is considered that the users perceive that the academic digital library satisfies outstandingly the subjective criterion sc_k. As in the case of the objective criteria, it increases the communication among the academic digital libraries with the aim of improving them. It increases the users' satisfaction and, therefore, the number of users accessing to the academic digital library and the number of queries that they execute.

4. A real case of application

In this section, we illustrate the application of the DSS proposed in this paper. To do so, we evaluate three Spanish academic digital libraries:

- Academic digital library of the University of Jaén.
- Academic digital library of the University of Córdoba.
- Academic digital library of the University of Granada.

First, it is necessary to comment some software aspects of the DSS. It is based on a LAMP stack [33] (GNU/Linux, Apache Web server, MySQL database, and PHP programming language), and it is fully Web-based, that is, all its components and options can be accessed through a Web interface. In Fig. 3, we show a snapshot of the DSS.

Before the DSS generates the recommendations to each academic digital library, we have to provide both the objective criteria and the subjective criteria to the DSS. As aforementioned in Section 3.1, the objective criteria are computed from the data provided by the different academic digital libraries. Once the objective criteria have been obtained, they are introduced into the DSS by the administrator of each academic digital library (see Fig. 4).

Fig. 3. Snapshot of the DSS.

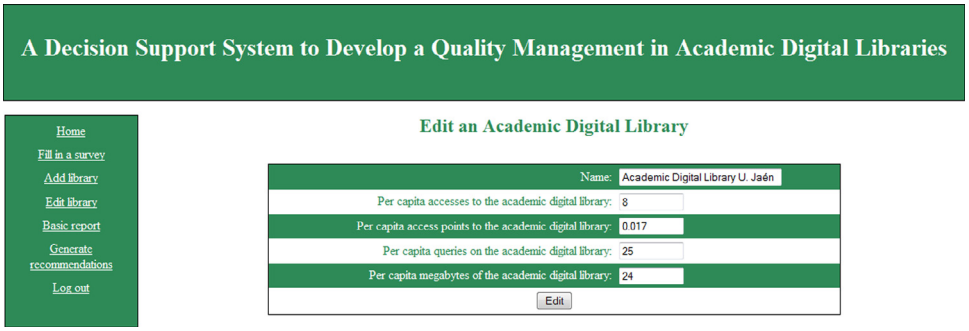

Fig. 4. Edit an academic digital library.

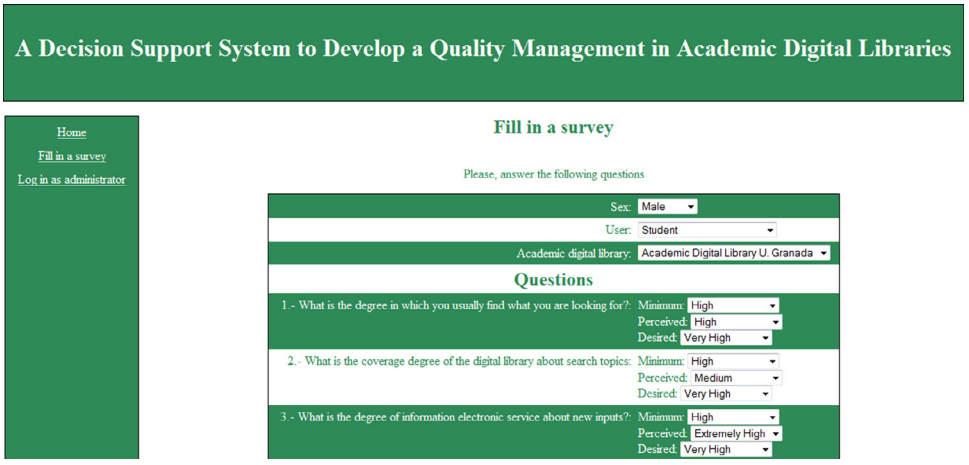

Fig. 5. Fill in a survey.

To obtain quality assessments of the subjective criteria, fifty subjects were recruited for this study in each university. They were students, Ph.D. students and teachers who were interested in the use of the academic digital libraries. They were invited to provide their judgments on the ten subjective criteria described in Section 3.3.2 using the set of nine linguistic labels shown in Section 2.1. They gave their opinions on the minimum service level required in each subjective criterion, on the desired service level, and on the perceived performance level. In Fig. 5, it can be seen an example of a survey filled by a student at the University of Granada.

Once both objective and subjective criteria have been obtained, the DSS generates a report which can be analyzed by the administrator of the academic digital library. This report is divided into two columns. The first one presents the information related to the objective criteria, whereas the second one presents the information about the subjective criteria. In Fig. 6, the report obtained in this study by the academic digital library of the University of Jaén is shown. On the one hand, in this particular study, we can observe that the subjective criterion sc_5 has a negative service adequacy score, that is, users think that navigability of the academic digital library should be improved. On the other hand, the subjective criterion sc_9 has a positive service adequacy score, which means that almost every user agrees on a good evaluation of the response time of the academic digital library.

Besides the report about each academic digital library, the main novelty of the DSS proposed in this paper is that it generates recommendations considering both objective and subjective criteria to improve the service and functionality of the services

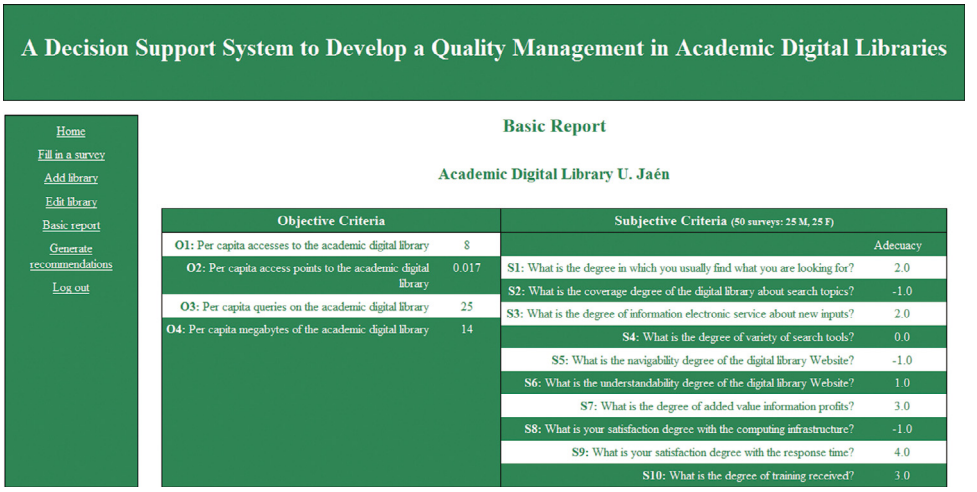

Fig. 6. Report.

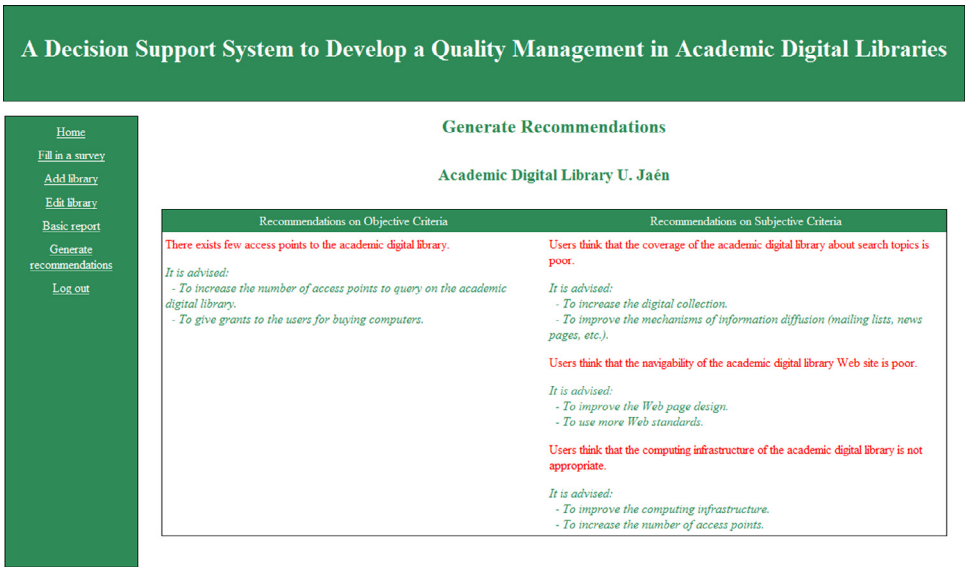

Fig. 7. Recommendations.

offered by the academic digital libraries in order to increase the number of users utilizing them. In Fig. 7, it is shown the recommendations generated by the DSS to the academic digital library of the University of Jaén, which are divided into two columns. Furthermore, each recommendation is composed of two parts. The first one (in red color) indicates the problem detected according to the users' judgments. The second one (in green color) provides the suggestions which are proposed to the staff of the academic digital library to solve the problem detected. These recommendations are expressed in natural language in order to facilitate their understanding to the staff of the academic digital library.

5. Conclusions and future work

Internet access has resulted in academic digital libraries that are increasingly used by diverse communities for diverse purposes, and in which sharing and collaboration have become important social elements. As academic digital libraries become commonplace, as their contents and services become more varied, people expect more sophisticated services from them. For this reason, we have presented a DSS which generates recommendations with the aim of improving the functionality and the service offered by the academic digital libraries and, in this way, to increase the number of both accesses and queries of their users. Its main innovation is that it is the first DSS which is proposed to develop a quality management in academic digital libraries, incorporating quality qualitative and quantitative criteria and decision rules to support the staff to make decisions.

In the future, we propose to continue this research approach by incorporating to the DSS different kinds of graphical outputs, as radar plots and ball graphs, to better understand the different quality assessments on each criterion that draw the quality situation of an academic digital library. For example, we will use some radar plots to compare a particular academic digital library against an average of the rest of academic digital libraries and, in such a way, to easily detect which particular criteria have better or worse evaluations than the average. We also think that it is necessary to incorporate information from the users' opinions expressed in social media by applying appropriate methods as those developed in [34]. Finally, it is important to note that the field of user experience represents an extension and expansion of the field of usability, to include the holistic perspective of how a user feels about using a system [35]. That is, there is a thin line separating the user web experience and the user information access experience [36] and, therefore, it has to be studied how this influences the qualitative assessments obtained.

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