A Performance Evaluation Method for Evaluating the Performance of Electronic Exam Systems

Abstract

This paper presents a performance evaluation method for evaluating the performance of appropriate electronic exam systems in the higher education environment. Linguistic terms are used for representing the decision maker's subjective assessments. To ensure the efficiency of the computation process, fuzzy numbers are used to approximate the linguistic terms in evaluating the relative importance of the evaluation criteria and the performance of individual electronic exam systems. To greatly reduce the cognitive demand on the decision maker, the pairwise comparison technique is adopted for evaluating the performance of alternative electronic exam systems and the relative importance of the evaluation criteria. The concept of ideal solutions is introduced for calculating an overall performance index for every electronic exam system alternative across all criteria. An example is presented for demonstrating the applicability of the performance evaluation method.

Keywords: Performance evaluation; Electronic exam systems; Multicriteria decision making; Selection; Higher education.

1 Introduction

Education is considered a socially-oriented activity and the quality of education is normally determined by the reputation of the provider, the associated academics and the support provided to the learners in enhancing their learning experience (Al-Sarmi et al. 2015; Oliver, 2003). The advancements in the area of Information and Communication Technologies (ICT) have created new opportunities to transform traditional learning and teaching practices. According to Queensland Government (2011), the use of technology in learning and teaching encourages high-order thinking, which is critical for problem solving. Many Universities agree that use of ICT tools by higher education providers has become a common practice in delivering courses because of the prospects they offer in improving students' learning experience (Gillard, 2008). This view is shared by Oliver (2003) who claims that education providers should adopt ICT into classrooms for delivering educational contents to students as it supports 'any place' and 'any time' learning and creates flexible learning environment.

In the recent years, the use of learning management systems (LMS) has increased significantly in the learning process, because LMS combine Internet technologies with several teaching tools to enhance communication between students and teachers, and improve the effectiveness of whole learning process (Fathema et al., 2015). A survey conducted by McManus (2012) at an Australian University suggests that at least 9 students out of every 10 owned mobile devices with Wi-Fi capabilities to use in Wi-Fi zones and both access learning materials and complete their course related tasks. Another survey conducted in 2015 at the University of Southern Queensland in Australia found that between 90% and 70% of the students own or use smartphones and tablet PCs respectively (Farley et al., 2015). This shows the popular use of technology in the higher education environment, and also students' familiarity with recent technologies, which can be considered for conducting electronic exams (Hiller and Fluck, 2013).

Pajo and Wallace (2001) believe that the success on the use of technology in education is dependent on how teachers embrace it. Traditionally, exams are conducted by the education provider at a designated exam hall. While it reduces exam cheating, it does not allow flexibility for students and particularly off-campus students are forced to travel longer distances to take exam on a scheduled day and time. This resulted in the adoption of different technologies by the higher education providers for supporting their learning and teaching practices. Although use of ICT in higher education has increased, many of the education providers are still behind with adopting suitable technologies for conducting exams online (Riddle and Howell, 2008).

Electronic exams can be defined as a system which allows exams to be conducted through the use of the Internet (Ayo et al., 2007). The purpose of conducting electronic exams is to provide (a) flexibility to students (Khare and Lam, 2008), (b) reduce cost, and (c) faster grading process (Kuikka et al., 2014). A study conducted by Hiller and Fluck (2013) suggests that electronic exams provide flexibility to students and also reduces the cost of conducting exams at Universities.

It is found that several Universities have gained the reputation for providing quality education online to reach out remotely located students and allow them to access materials and submit their assignments online through LMS (Grattan Institute, 2014). At the moment, there are several providers offering electronic exam system with range of features in their products. However, the main concern is on how these Universities can adopt an appropriate electronic exam system to conduct exams for enhancing students' learning experience. The problem can be more concerning for the Universities choosing to become leading online education providers. Hence, there is a need to study relevant dimensions and criteria leading to the successful adoption of electronic systems for helping Universities promote their programs and enhance students' learning experience.

This paper presents a performance evaluation method for evaluating the performance of appropriate electronic exam systems in the higher education environment. Linguistic terms are used for representing the decision maker's subjective assessments. To ensure the efficiency of the computation process, fuzzy numbers are used to approximate the linguistic terms in evaluating the relative importance of the evaluation criteria and the performance of individual electronic exam systems. To greatly reduce the cognitive demand on the decision maker, the pairwise comparison technique is adopted for evaluating the performance of alternative electronic exam systems and the relative importance of the evaluation criteria. The concept of ideal solutions is introduced for calculating an overall performance index for every electronic exam system alternative across all criteria. An example is presented for demonstrating the applicability of the performance evaluation method.

In what follows, we first present an introduction of the electronic exam system performance evaluation problem. We then develop a performance evaluation method for dealing with the electronic exam system performance evaluation problem. Finally we present an example to demonstrate the applicability of the proposed performance evaluation method for dealing with the real electronic exam system performance evaluation problem.

2 Performance Evaluation Problem of Electronic Exam Systems

Evaluating the performance of the appropriate electronic exam systems usually involves in (a) assessing the performance ratings of available electronic exam systems with respect to each criterion, and the relative importance of the evaluation criteria, (b) determining the criteria weighting and performance rating of electronic exam systems, (c) aggregating the fuzzy criteria weightings and performance ratings for producing a weighted fuzzy performance matrix, and (d) calculating an overall performance index for each electronic exam system across all criteria.

In order to evaluate the performance of the available electronic exam systems, it is important to firstly define the suitable performance dimensions and criteria for ensuring that the performance measurement produces an accurate and effective result. This is because not every performance dimension and criterion is relevant to the specific individual's requirements (Wibowo and Deng, 2012). Much research has been conducted in identifying the relevant criteria for evaluating and selecting software systems from different perspectives (Dearnley et al., 2009; Oketunji, 2006; Sahay and Gupta, 2003). Sahay and Gupta (2003) divide software selection criteria into primary and secondary drivers. They state that technology, cost of the software, features, customizability and support services are primary drivers, while the secondary drivers consist of vendor vision, strength and software capabilities. DeLone and McLean (2003) argue that quality relating to overall system, information and service quality along with usability are the key factors in successful implementation of systems. Meanwhile, Edwards et al. (2002) point out additional factors including system functionality, information and support quality need to be taken into account while conducting the software selection process.

Lee et al. (2005) and Oketunji (2006) state that software should be selected on the basis of its ability to support users in carrying out tasks efficiently through its features, encourage creativity, support it offers in the form of clear instructions and vendor reputation. Meanwhile, Dearnley et al. (2009) believe that perceived usefulness of the system and the enjoyment influence learner intention to use the system.

A comprehensive review of the related literature shows that four important dimensions and fifteen criteria are relevant for evaluating the performance of electronic exam systems. The four dimensions include (a) System quality, (b) Information quality, (c) Service quality, and (d) Attractiveness.

2.1 System quality

System quality refers to the conformance to user requirements. It is the expected performance of a system with appropriate functionality that would be sufficient for the users to carry out specific tasks. It is very unlikely that software would be free from bugs. Therefore, vendors are expected to ensure that the software is thoroughly tested to meet the quality standards (Laudon and Laudon, 2011).

Standardized environment, accessibility, availability and flexibility are considered to be the key criteria for determining the system quality (DeLone and McLean, 2003). In case of electronic exam systems, quality is determined by its ability to allow academic staffs to create, distribute, conduct exams, grade students’ responses and obtain feedback on students’ performance. For the case of students, the system has to offer accessibility (Teo et al., 2003), better response time (Jadhav and Sonar, 2009), flexibility (Laudon and Laudon, 2011), navigability (Huizingh, 2000), and additional support for easy learning (Palmer, 2002) as these systems are expected to improve the overall exam experience to both academic staffs and students.

2.1.1 Accessibility

It refers to electronic exam systems' ability to provide easy access to its users. Huizingh (2000) believes that the users' willingness to use a specific source will be influenced by the perceived accessibility or an effort required for using it. Accessibility deals with the level of effort required to access the system. The electronic exam systems should allow the creation of web links, which can be used by the examinees to access the exam. Once students are provided with exam link, they would try accessing the exam through web browsers. The electronic exam system should be compatible with multiple browsers as choice of web browser is dependent on individuals and sometimes operating system specific. Failure to be compatible with multiple web browsers can prevent students from completing exams.

2.1.2 Navigability

Navigability refers to the arrangement to allow users to find what they are looking for. System navigability is a quality aspect relating to the system design, which is often considered very important as it determines the usability (Levene, 2001). In a traditional physical exam setting, students will be provided with a question paper, which allows them to move from one question to the other easily. The electronic exam system should include features that permit students to switch from one question to the other. This enables students to return to unanswered questions and also provides flexibility to answer the questions in their preferential order. Levene (2001) points out that the adoption of an appropriate scheme for easier navigation can improve user satisfaction.

2.1.3 Response time

System reliability in a real-time is measured by the response time. Response time refers to the time taken to provide a response for a request made by user for specific action or information. Response time specifications are important for the real-time operation of software (Lee and Lin, 2005). As exams impose time limitations, it is important to ensure faster response times. Examinees would be unlikely to continue the exam in case of poor response times and significant delays in fulfilling their requests. Therefore, faster response rates are needed are necessary for real-time operation.

2.1.4 Learnability

Learnability refers to level of complexity with learning and operating the software (Jadhav and Sonar, 2009). Exams create anxiety and students attending the exam are more focused on completing the exam rather than learning new system and exploring the system features. It is important to embed most common features such as timer, navigation buttons and help menu, and make them visible. Improper distribution of different buttons on the page can destroy students' enthusiasm in answering questions.

2.2 Information quality

Information quality related to the information provided to the users. Accurate and most up to date information is considered part of quality information (DeLone and McLean, 2003; Nelson et al., 2005). Invigilators are made present in the traditional exam setting and they provide clarification on the questions by seeking responses from the subject expert. However, electronic exams limit this interaction. Presenting high quality information improves understanding and support timely completion of tasks. If the presented information is inaccurate the examinees may tend to doubt, which would negatively impact acceptance rates

(Wixom and Todd, 2005). Currency, completeness and format are considered to be the relevant criteria for determining information quality.

2.2.1 Currency

Currency refers to most up-to-date information (Nelson et al., 2005). Most recent information supports timely completion of tasks. It is an obligation for the academic staffs to provide most current information to direct students. Also, updated information will help to improve students' understanding of the topic.

2.2.2 Completeness

Completeness refers to availability of necessary information to use the system. While up-to-date information is critical in students understanding, providing details can encourage interpretation (Nelson et al., 2005). Information relating to the features can increase the use of these features. Electronic exam systems offer range of features, such as review options for students to revise their answers during examination. Academic staffs are usually provided options to reuse questions in different examinations, review student grades and compare students responses for each question and be able to email grades to students. It is important to note that not all the options provided would be used by the users in every scenario, but students are to be provided with all necessary information to complete the exam. Similarly, academic staffs should be given sufficient information to create exams.

2.2.3 Format

It refers to how the information should be organized for easier understanding to the students (Wixom and Todd, 2005). Electronic exam tools allow trainers to choose predefined templates and forms. Choosing the right format can enhance students understanding of the requirements.

In general, exams are prepared well in advance and undergo several changes during the moderation process. For example, time zones may vary depending on the location and some states in Australia have day light savings in summer, such scenarios are to be well thought and relevant information should be incorporated to make it current. Failure to incorporate current information can lead to confusion and may affect students’ performance in the exam.

2.3 Service quality

Service quality refers to the overall support offered to the users (Cao et al., 2005; Lee and Lin, 2005) and it is measured by the level of service provided by the system (Nelson et al., 2005). Jadhav and Sonar (2009) believe that reliable service, responsiveness, trust and empathy criteria should be considered for assessing the service quality of the system. In traditional exam settings, students need to communicate with invigilators to seek responses for their questions, whereby this face-to-face interaction is not necessary in the use of electronic exams. If the students fail to complete the exam due to unclear description of questions, incomplete information or technical issues, then there should be sufficient mechanisms to assist students. The commitment to offering quality service is demonstrated by the continuous efforts to improve service quality. High quality services encourage students to communicate with their academic staffs immediately to resolve issues.

2.3.1 Reliability

It is the capability of the system to function smoothly without crashing (Jadhav and Sonar, 2009). Reliability is a quality characteristic and it can be assessed by repeated testing of the system. In order to ensure reliability of electronic exams, there is a need to test the usability and its performance.

2.3.2 Responsiveness

It refers to the preparedness to support users and providing appropriate response (Wixom and Todd, 2005). Exams cause stress and students generally contact their academic staffs before and after their exams to seek responses for their questions. Poor responses or delays in responding can be increase stress level. During exams, responsiveness can be improved by using features such as online chat.

2.3.3 Trust

It is the user's preparedness to accept liability based on their past experiences (Kimery and McCard, 2002). Interestingly, a research conducted by Zuboff (1988) found that people do not trust new technologies. However, individual's willingness to accept new system improves with high levels of privacy and security (Ong et al., 2004).

2.3.4 Empathy

Empathy refers to the capacity to understand another person's view and condition. Every student is unique so as their needs. Students from non-IT background would struggle to use features embedded in the electronic exam system. Similarly, students with special needs may require additional support and attention. Personalized support, acknowledgement and compliments for valuable suggestions demonstrate empathy towards students (Yang, 2001). In fact, empathy is proven to improve overall communication.

2.4 Attractiveness

It refers to the visual appearance and attractiveness of the system which is dependent on several criteria including the presentation of the content, the layout, the design and the choice of colors (Ranganathan and Ganapathy, 2002). Users find systems attractive when the information is easily accessible (Harrison et al., 2005) and tend to participate (van der Heijden, 2003). It is also found that users normally consider the visual attractiveness of the system while assessing the quality of the system (Ranganathan and Ganapathy, 2002), which helps to increase users' willingness to use the system. The attractiveness dimension is usually measured by the multimedia capability, the interface design, the visual clarity of the system, and the enjoyment of using the system.

2.4.1 Multimedia capability

It refers to the system's ability to offer multimedia features such as audio, video clips and animation. These features improve users' understanding of the content (Cao et al., 2005). In a paper based exam, academic staffs have the option to use images and base their questions on these. Electronic exam systems allow academic staffs to upload images, audios and videos which can be used to test students understanding of different topics.

2.4.2 Interface design

Interface design refers to visually attractive and very well organized user interface. Well-designed interfaces can be appealing (Law and Leung, 2000) to students and improve their participation. Electronic exam systems come with predefined templates, but it is the task of academic staffs to ensure that the interacting page is attractive and organized.

2.4.3 Visual clarity

While interface design with multimedia capabilities makes the system attractive, it is also important to ensure that the capabilities adopted in the system are relevant, usable and offers visual clarity. Usability of a system can be improved through user scenarios, which helps to understand users' requirements and meet design objectives relating to the logical arrangement of the features (Deng and Poole, 2010). This will enable academic staffs to develop exams and students to complete exams successfully by using the available system features.

2.4.4 Enjoyment

Enjoyment refers to user's positive response while using the system. In order to create positive experience to the user, system should facilitate features with clear instructions to allow completion of tasks (Oketunji, 2006). According to Lee et al. (2005), if the users perceived the system to be useful and easy to use then they would tend to use it frequently. Mora et al. (2012) also noted that perceived usefulness and positive experience lead to user acceptance.

To address these issues discussed above, the next section presents the performance evaluation method for evaluating the performance of electronic exam systems, which will provide a platform for choosing the appropriate exam systems to be developed and implemented.

3 The Performance Evaluation Method

Evaluating the performance of electronic exam systems is complex and challenging. This is due to (a) the conflicting nature of multiple evaluation criteria, and (b) fuzzy data derived from imprecise judgments of qualitative performance ratings resulting from human subjectivity (Yeh et al., 2010; Wibowo and Deng, 2012). To adequately solve this problem, it is therefore desirable that a structured method capable of comprehensively evaluating the overall performance of available electronic exam systems with respect to the multiple evaluation criteria in a specific decision setting.

In this paper, the performance evaluation of electronic exam systems process is modeled as a multicriteria decision making problem where the process usually involves in (a) discovering all available alternatives, (b) identifying the performance evaluation criteria, (c) assessing the alternatives' performance ratings and the criteria weights by the decision maker, (d) aggregating the alternative ratings and criteria weights for producing an overall performance index for each alternative across all the criteria, and (e) selecting the best alternative in the given situation (Yeh et al., 2010; Wibowo and Deng, 2013).

Subjective assessments are usually involved in the electronic exam systems' performance evaluation process. In this paper, the fuzzy pairwise comparison process is conducted by the decision maker to assess: (a) the relative importance of each performance dimension, (b) the relative importance of each criterion under each performance dimension, and (c) the relative performance of each electronic exam system alternative with respect to each criterion.

To facilitate the subjective evaluation process, linguistic terms can be used for representing the subjective assessments of the decision maker. To ensure the efficiency of the computation process, triangular fuzzy numbers are often used to approximate these linguistic terms. Fuzzy numbers are widely used to approximate the linguistic terms used for expressing the decision maker's subjective assessments in the decision making process. To facilitate the making of pairwise comparison, linguistic terms originally defined by Saaty (1990) in the development of the analytical hierarchy process (AHP) approach are used. Table 1 shows the linguistic terms and their corresponding triangular fuzzy numbers for the decision maker to make qualitative assessments about the performance rating of each electronic exam system alternative with respect to a given criterion.

Table 1 Linguistic terms and their fuzzy number approximations for pairwise comparison assessments on relative performance of alternatives

Linguistic terms	Fuzzy number	Membership function
Very Poor (VP)	$\tilde{1}$	(1, 1, 3)
Poor (P)	$\tilde{3}$	(1, 3, 5)
Fair (F)	$\tilde{5}$	(3, 5, 7)
Good (G)	$\tilde{7}$	(5, 7, 9)
Very Good (VG)	$\tilde{9}$	(7, 9, 9)

Table 2 shows the linguistic terms and their corresponding triangular fuzzy numbers for the decision maker to make qualitative assessments about the relative importance of the criteria.

Table 2 Linguistic terms and their fuzzy number approximations for pairwise comparison assessments on criteria weights

Linguistic terms	Fuzzy number	Membership function
Equally important (EI)	$\tilde{1}$	(1, 1, 3)
Moderately important (MI)	$\tilde{3}$	(1, 3, 5)
Strongly important (SI)	$\tilde{5}$	(3, 5, 7)
Very strongly important (VI)	$\tilde{7}$	(5, 7, 9)
Extremely important (XI)	$\tilde{9}$	(7, 9, 9)

To solve the pairwise comparison matrices, the concept of fuzzy synthetic analysis is used. Assume that $X = \{x_1, x_2, ..., x_n\}$ is an object set, and $U = \{u_1, u_2, ..., u_m\}$ is a goal set. Fuzzy assessments are performed with respect to each object for each goal respectively, resulting in m extent analysis values for each object, given as $\mu_i^1, \mu_i^2, ..., \mu_i^m, i = 1, 2, ..., n$, where all μ_i^j ($i = 1, 2, ..., n; j = 1, 2, ..., m$) are fuzzy numbers representing the performance of the object x_i with regard to each goal u_j.

The concept of fuzzy extent analysis is used for deriving criteria weights and alternative performance ratings from the reciprocal matrices resulting from the pairwise comparison process (Chang, 1996). Due to its simplicity in concept and computational efficiency, the concept of fuzzy synthetic analysis has been employed in a number of applications including supplier selection (Shaw et al., 2012), automotive purchase (Sakthivel et al., 2013), power substation location selection (Kabir and Sumi, 2014), evaluation of risk factors in public-private partnership water supply projects (Ameyaw and Chan, 2015), evaluation of ship operational energy efficiency (Besikci et al., 2016), and green project selection (Zhao et al., 2016).

By using fuzzy synthetic extent analysis, the value of fuzzy synthetic extent with respect to the i^{th} object x_i (i = 1, 2, ..., n) that represents the overall performance of the object across all goals involved can be determined by

$$S_i = \frac{\sum_{j=1}^{m} \mu_i^j}{\sum_{i=1}^{n} \sum_{j=1}^{m} \mu_i^j} \tag{1}$$

The electronic exam system performance evaluation problem usually consists of a set of available electronic exam system alternatives A_i (i = 1, 2, …, n), to be evaluated against multiple evaluation criteria C_{ij} (j = 1, 2, …, m). The decision maker is usually required to make subjective assessments for evaluating the performance of each alternative with respect to each criterion, denoted as x_{ij} (i = 1, 2, …, n, j = 1, 2, …, m). The performance evaluation process starts with the determination of the performance of electronic exam systems with respect to each criterion and the relative importance of the evaluation criteria. To greatly reduce the cognitive demand on the decision maker in the performance evaluation process, the pairwise comparison technique is applied.

The fuzzy pairwise comparison assessments for all n alternatives produce a positive $n \times n$ fuzzy positive reciprocal matrix with all its elements $a_{ij} = 1/a_{ij}$ (i = 1, 2, …, n; j = 1, 2, …, n). Solving fuzzy positive reciprocal matrix will generate the relative fuzzy performance ratings (or fuzzy weights) for all the available alternatives. In this paper, the geometric mean method (Buckley, 1985) is applied to calculate the fuzzy weights for all the alternatives. Given a fuzzy positive reciprocal matrix $R = [a_{ij}]$, the geometric mean method first calculates the geometric mean of each row as in (2).

$$r_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{\frac{1}{n}} \tag{2}$$

The relative fuzzy performance ratings for *n* alternatives (or relative fuzzy weights for *n* criteria) w_i can then computed by using (3).

$$w_i = \frac{r_i}{\sum_{j=1}^{n} r_j} \tag{3}$$

The fuzzy pairwise comparisons with fuzzy ratios and equations (2) and (3) are used to obtain: (a) the relative importance w_j of each performance dimension C_i , (b) the relative importance of each criterion w_{jk} under each performance dimension, and (c) the relative performance of each electronic exam system alternative x_{ij} with respect to each criterion. The arithmetic operations on fuzzy numbers are based on fuzzy arithmetic (Kaufmann and Gupta, 1991).

The weighted fuzzy performance matrix that represents the overall performance of each electronic exam system alternative with respect to each criterion under each performance dimension can be determined as in (4).

$$Z = \frac{w_j x_{ij}}{\sum_{k=1}^{p_j} w_{jk}} \tag{4}$$

where w_{jk} ($k = 1, 2, \ldots, p_j$) is the criteria weighting for the criteria and x_{ij} is the performance rating of alternative A_i with respect to criterion C_{ij}.

It is often desirable to take the degree of confidence of the decision maker into consideration in order to make effective decisions where fuzzy alternative ratings and fuzzy criteria weights are present. To deal with this issue, a concept based on $\lambda(0 \le \lambda \le 1)$ is introduced for reflecting the decision maker's level of confidence in approximating his/her subjective assessment. The value of λ represents the decision maker's degree of confidence in his/her subjective assessment. λ = 0 signifies that the degree of confidence is the least while λ = 1 signifies that the degree of confidence is the most. A larger λ value indicates a more confident decision maker, meaning that the decision maker's assessments are closer to the most possible value b_i of the triangular fuzzy numbers (a_1, a_2, a_3) (Wibowo and Deng, 2013). Based on this concept, the refined assessment of the decision maker in regards to his/her level of confidence is defined as

$$Z_{ij}^{\lambda} = (a_1 + \lambda(a_2 - a_1), a_2, a_3 - \lambda(a_3 - a_2)) \tag{5}$$

where a_1, a_2, and a_3 are the lower bound, middle bound, and upper bound of individual decision maker's assessments about the performance rating of alternative A_i with respect to criterion C_j respectively.

Having already incorporated the individual decision maker's level of confidence as in (5), the fuzzy performance matrix for individual decision makers can be obtained as in (6).

$$Z^{\lambda} = \begin{bmatrix} z_{11}^{\lambda} & z_{12}^{\lambda} & . & z_{1m}^{\lambda} \\ z_{21}^{\lambda} & z_{22}^{\lambda} & . & z_{2m}^{\lambda} \\ . & . & . & . \\ z_{n1}^{\lambda} & z_{n2}^{\lambda} & . & z_{nm}^{\lambda} \end{bmatrix} \tag{6}$$

In practical applications, λ = 1, 0.5, or 0 can be used respectively to indicate that the decision maker involved has an optimistic, moderate, or pessimistic view in the evaluation process

(Wibowo and Deng, 2012). An optimistic decision maker is apt to prefer higher values of his/her fuzzy assessments, while a pessimistic decision maker tends to favor lower values.

Given the fuzzy vector of the performance matrix for criterion C_j, a fuzzy maximum ($M^j_{\max}$) and a fuzzy minimum ($M^j_{\min}$) (Hwang and Yoon, 1981) can be determined as in (7)-(8) which represent respectively the best and the worst fuzzy performance ratings among all the alternatives with respect to criterion C_j.

$$\mu_{M^j_{\max}}(z^\lambda) = \begin{cases} \dfrac{z^\lambda - z^{\lambda j}_{\min}}{z^{\lambda j}_{\max} - z^{\lambda j}_{\min}} \\ 0, \end{cases} \tag{7}$$

$$\mu_{M^j_{\min}}(z^\lambda) = \begin{cases} \dfrac{z^{\lambda j}_{\max} - z^\lambda}{z^{\lambda j}_{\max} - z^{\lambda j}_{\min}} \\ 0, \end{cases} \tag{8}$$

where $z^{\lambda j}_{\max} = \sup \bigcup_{i=1}^{n} (z^\lambda_{ij})$ and $z^{\lambda j}_{\min} = \inf \bigcup_{i=1}^{n} (z^\lambda_{ij})$.

The degree to which alternative A_i is the best alternative with respect to criterion C_j can then be determined by calculating the Hamming distance between its weighted fuzzy performance ($w_j x_{ij}$) with the fuzzy maximum and the fuzzy minimum (Chen, 1985) respectively, given as in (9) and (10) respectively.

$$h_i^{\lambda +} = (\sum_{j=1}^{m} H(w_j x_{ij} - M^j_{\max}) \tag{9}$$

$$h_i^{\lambda -} = (\sum_{j=1}^{m} H(w_j x_{ij} - M^j_{\min}) \tag{10}$$

Based on (11), the overall performance index for each alternative with the decision maker's λ level of confidence can be determined. The larger the performance index P_i, the more preferred the alternative A_i.

$$P_i^{\lambda} = \frac{h_i^{\lambda+}}{h_i^{\lambda+} + h_i^{\lambda-}} \tag{11}$$

The performance evaluation method presented above can be summarized as follows:

Step 1: Assess the performance of alternative A_i with respect to criteria C_{ij} under each performance dimension C_i using fuzzy assessments with the linguistic terms given in Table 1.

Step 2: Specify the preferred weights for the criteria C_{ij} and the performance dimensions C_i using fuzzy pairwise comparisons with the linguistic terms given in Table 2.

Step 3. Obtain the relative importance of the criteria w_{jk}, the relative importance of the performance dimensions w_j, and the relative performance of the alternatives x_{ij} by solving the fuzzy positive reciprocal matrices by (2) and (3).

Step 3. Calculate the weighted fuzzy performance matrix by using (4).

Step 5. Determine the level of confidence of the decision maker by using (5).

Step 6. Determine the fuzzy maximum and the fuzzy minimum which represent the best and worst fuzzy performance ratings among all the alternatives by (7) and (8) respectively.

Step 7. Calculate the Hamming distance between its weighted fuzzy performance with the fuzzy maximum and the fuzzy minimum respectively, given as in (9) and (10) respectively.

Step 8. Compute the overall performance index for each alternative by (11).

Step 9. Rank the alternatives in descending order of their overall performance index values.

4 An Example

To demonstrate the applicability of the proposed performance evaluation method, we present an example of evaluating and selecting an electronic exam system at a higher education provider in India.

The Indian private higher education provider Symbiosis Centre for Distance Learning (SCDL) is based in an Indian city of Pune with over 550 employees and offers business, law and information technology programs to more than 200,000 students across India and over 40 different countries pursuing various programs through distance learning. It has state-of the art technologies in its library, labs and classrooms for connecting to its local centers spread across India and facilitate videoconferencing through virtual private network (Mujumdar, 2011).

SCDL has not only created a large network of study centers, but it is a pioneer in developing many ICT solutions and facilities to improve the quality, accessibility, delivery and reach of education to thousands of distant learners. SCDL offers blended learning programs combining self-learning material, e-learning, online learning and faculty-based learning. The use of innovative technology solutions has helped SCDL to achieve academic and operational excellence. SCDL has some 150 employees and also uses the expertise of over 400 visiting faculty members. As the programs are offered online, there is a need to conduct exams throughout the academic year. This warrants the need for flexibility in conducting more evenly distributed exams. This issue is further complicated by the fact that around 500,000 exams are expected to be taken by the students in each academic year (Mujumdar, 2011).

Based on a thorough investigation, three electronic exam software are identified for development and implementation at SCDL. They are (a) Exam Pro, (b) TAO, and (c) TCExam. Exam Pro is a USA-based electronic exam software that aims to develop educational software at an affordable price to allow educational institutions to use its software for conducting electronic exams. Exam Pro software is one of the reputable tools used by organizations in different industries including education, health, government, engineering, telecommunications and banking around the world for conducting online exams. The software offers a user-friendly graphical user interface that allows academic staffs to develop electronic exams consisting of different questions types such as multiple choice questions (MCQs), True/False question types and essay type questions (Exam-software, 2015).

The major advantage of Exam Pro is that it provides “royalty free” distribution rights, which allow the buyer to install the software on multiple desktop computers, adopt their own company logos and also develop and sell customized test packages. The packages offer customization by allowing academic staffs to set startup image, company logo image, background colors, images and font styles. It also provides multiple language support to create test/exam/quiz in different languages. Once the tests are developed by the academic staffs, these will be packaged into an executable program to conduct computer based online examination. In addition, the software allows examiners to administer exams remotely with a high emphasis on security by placing the exam questions on central server, which can be accessed by the students from multiple locations (Exam-software, 2015).

TAO is a commercial-grade open source, electronic exam software based on a joint project between the Luxembourg Institute for Science and Technology and the University of Luxembourg. It offers complete control to the users by allowing them to define their own requirements and data models. The developed tests can be administered to more than 100,000 users at a time from any computer over the cloud and also be integrated to LMS. It stores the data on server-side to enhance security and also offers freedom in using devices to access tests. Upon completing the tests, users are provided with individual feedback for improvements and the detailed reports allow academic staffs to gain in-depth understanding of the whole group performance and make comparisons (Open Assessment Technologies, 2016).

TCExam is an open-source electronic exam software for managing exams, tests, surveys and quizzes. The software is aimed to simplify the evaluation process at educational institutions and both commercial and public organizations. Several education providers and the businesses are among 180,000 users. It is a web-based and platform independent software that permits users to switch between 24 different languages and include new functionalities such as improved translation and localization with universal availability of content (TCExam, 2012).

The general advantages of TCExam include the automation of all assessment phases from developing test materials, scheduling of exams, conducting exams online, creating grade reports instantly and to sending them to students electronically by email. Some of the features include user-friendly interface that allows connectivity to TCExam software through most commonly used web browsers, improved security, consistency, reusability of exam questions and faster reporting mechanism (TCExam, 2012).

To start with the performance evaluation process, SCDL organized a steering committee to facilitate the organization transformation. A consensus agreement is reached based on a thorough investigation about the criteria for evaluating the performance of electronic exam systems. Four most important performance dimensions and fourteen criteria are identified for evaluating the performance of electronic exam systems. The four performance dimensions include System quality (C_1), Information quality (C_2), Service quality (C_3), and Attractiveness (C_4). Three alternatives are identified for the performance evaluation purpose. The hierarchical structure for evaluating the performance of electronic exam systems is shown in Figure 1.

A comprehensive investigation has been carried out to collect the required data for the evaluation process. Subjective assessments are usually involved in evaluating the performance of alternative electronic exam systems and the importance of the evaluation criteria. To facilitate the subjective evaluation process, linguistic terms are used for representing the subjective assessments of the decision maker. To ensure the efficiency of the computation process, fuzzy numbers are used to approximate the linguistic terms in the performance evaluation process.

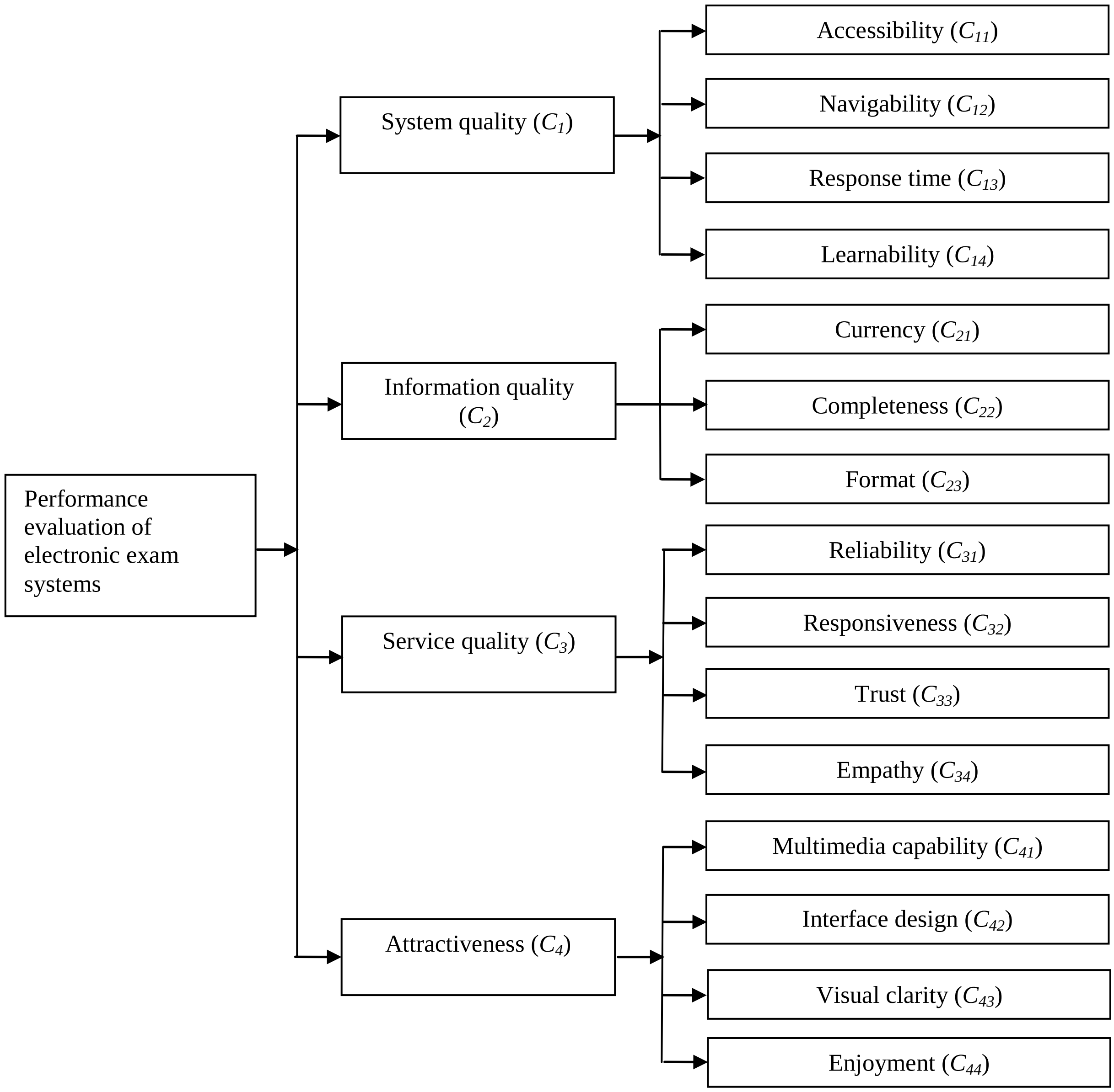

Figure 1 The hierarchical structure for evaluating the performance of electronic exam systems

It is observed that two common issues are involved in this electronic exam systems evaluation and selection process. The evaluation criteria are generally multi-dimensional in nature and a simultaneous consideration of those multiple criteria is required for making effective selection decisions. In addition, the evaluation process involves subjective assessments, resulting in qualitative and vague data being used.

The performance evaluation of electronic exam systems process starts with instructing the decision maker to enter the set of alternatives and criteria to be used for evaluating electronic exam systems. Using the pairwise comparison technique based on the linguistic terms defined as in Table 1, the performance ratings of alternative electronic exam systems in regard to each criterion can be determined as shown in Table 3.

In order to determine the relative importance of the evaluation criteria, pairwise comparison is used based on the linguistic terms defined as in Table 2, resulting in the determination of a fuzzy judgment matrix as shown in Table 4. By applying (2) and (3) to the assessment results, the relative importance of the criteria and the relative performance of the electronic exam system alternatives with respect to each criterion are obtained. Tables 5 and 6 show the results.

Table 3 Performance assessments of the electronic exam systems

Alternatives	Fuzzy assessments														
	System quality (C_1)				Information quality (C_2)			Service quality (C_3)				Attractiveness (C_4)			
	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A_1	G	F	G	VG	G	G	G	F	G	F	G	G	G	F	G
A_2	F	F	G	G	VG	F	F	F	F	G	F	VG	F	F	F
A_3	G	F	G	G	G	G	G	G	F	F	G	F	G	G	F

Table 4 The relative importance of the criteria

	System quality (C_1)				Information quality (C_2)			Service quality (C_3)				Attractiveness (C_4)			
Fuzzy assessments	VI				EI			VI				MI			
	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
Fuzzy assessments	SI	VI	VI	EI	XI	VI	MI	VI	VI	VI	EI	MI	EI	MI	MI

Table 5 Relative performance of the electronic exam systems

Alternatives		Relative performance		Relative performance		
A_1	C_{11}	(0.062, 0.142, 0.227)	C_{12}	(0.029, 0.043, 0.076)	C_{13}	(0.193, 0.376, 0.638)
A_2		(0.162, 0.318, 0.538)		(0.082, 0.164, 0.378)		(0.139, 0.326, 0.636)
A_3		(0.037, 0.108, 0.219)		(0.163, 0.219, 0.374)		(0.076, 0.261, 0.483)
A_1	C_{14}	(0.009, 0.173, 0.216)	C_{21}	(0.106, 0.183, 0.349)	C_{22}	(0.154, 0.387, 0.569)
A_2		(0.048, 0.175, 0.327)		(0.137, 0.439, 0.583)		(0.283, 0.483, 0.694)
A_3		(0.035, 0.071, 0.116)		(0.254, 0.431, 0.679)		(0.083, 0.267, 0.492)
A_1	C_{23}	(0.032, 0.053, 0.097)	C_{31}	(0.062, 0.278, 0.435)	C_{32}	(0.272, 0.561, 0.659)
A_2		(0.142, 0.316, 0.673)		(0.142, 0.256, 0.463)		(0.137, 0.362, 0.519)
A_3		(0.054, 0.264, 0.439)		(0.094, 0.230, 0.436)		(0.093, 0.157, 0.192)
A_1	C_{33}	(0.118, 0.254, 0.437)	C_{34}	(0.146, 0.247, 0.516)	C_{41}	(0.026, 0.049, 0.086)
A_2		(0.074, 0.334, 0.683)		(0.016, 0.168, 0.225)		(0.024, 0.040, 0.072)
A_3		(0.271, 0.437, 0.595)		(0.037, 0.158, 0.338)		(0.081, 0.164, 0.336)
A_1	C_{42}	(0.027, 0.053, 0.126)	C_{43}	(0.045, 0.063, 0.106)	C_{44}	(0.135, 0.197, 0.267)
A_2		(0.168, 0.319, 0.549)		(0.125, 0.428, 0.597)		(0.154, 0.336, 0.551)
A_3		(0.045, 0.106, 0.242)		(0.262, 0.446, 0.735)		(0.262, 0.547, 0.834)

Table 6 Relative importance of the criteria

Criteria	Relative importance
C_{11} Accessibility	(0.144, 0.186, 0.227)
C_{12} Navigability	(0.138, 0.239, 0.358)
C_{13} Response time	(0.218, 0.352, 0.553)
C_{14} Learnability	(0.073, 0.137, 0.264)
C_{21} Currency	(0.162, 0.283, 0.461)
C_{23} Completeness	(0.239, 0.467, 0.751)
C_{31} Reliability	(0.051, 0.167, 0.354)
C_{32} Responsiveness	(0.432, 0.634, 0.895)
C_{33} Trust	(0.086, 0.249, 0.416)
C_{34} Empathy	(0.369, 0.614, 0.837)
C_{41} Multimedia capability	(0.203, 0.476, 0.573)
C_{42} Interface design	(0.257, 0.462, 0.649)
C_{43} Visual clarity	(0.103, 0.364, 0.518)
C_{43} Enjoyment	(0.126, 0.237, 0.426)

The weighted fuzzy performance matrix for the electronic exam systems' performance evaluation problem with respect to each criterion can then be determined. In this case, the decision maker has a medium level of confidence, and $\lambda = 0.5$ is applied to (5). Based on (6)-(9), the positive ideal solution (or the electronic exam system with the best relative performance) and the negative ideal solution (or the electronic exam system with the worst relative performance) of all electronic exam system alternatives with respect to each criterion under each performance dimension can calculated. Table 7 shows the results.

Table 7 Weighted performance value (λ = 0.5)

Performance dimension	System quality (C_1)	Information quality (C_2)	Service quality (C_3)	Attractiveness (C_4)
Positive ideal solution	(0.237, 0.114, 0.076)	(0.306, 0.128, 0.053)	(0.349, 0.158, 0.093)	(0.294, 0.189, 0.089)
Negative ideal solution	(0.066, 0.043, 0.021)	(0.057, 0.039, 0.013)	(0.104, 0.086, 0.047)	(0.086, 0.057, 0.022)

Based on (10), the overall fuzzy performance index for each electronic exam system alternative across all the criteria can be calculated. Table 8 shows the overall fuzzy performance index values of the electronic exam systems and their corresponding rankings. Alternative A_1 is the best electronic exam system, as compared to the other available alternatives with the overall fuzzy performance index of 0.662.

Table 8 The performance index and ranking of electronic exam systems for all performance dimensions

	A_1	A_2	A_3
System quality (C_1)			
Index	0.703	0.669	0.517
Ranking	1	2	3
Information quality (C_2)			
Index	0.615	0.584	0.672
Ranking	2	3	1
Service quality (C_3)			
Index	0.648	0.552	0.604
Ranking	1	3	2
Attractiveness (C_4)			
Index	0.648	0.586	0.693
Ranking	2	3	1
Index	0.662	0.573	0.634
Overall ranking	1	3	2

The result in Table 8 provides the management of the higher education provider with information about the relative performance level of individual electronic exam systems for all performance dimensions. Although alternative A_1 has a dominating position in overall performance, it does not have the best performance in all performance dimensions. This comparative status also applies to other electronic exam system alternatives. This result demonstrates the conflicting nature of electronic exam system performance evaluation dimensions and suggests that single performance dimension alone, cannot capture the notion of overall electronic exam system's performance. For example, despite being the best performer, alternative A_1 requires improving its information quality and the attractiveness dimensions. Alternative A_2 can put more efforts on system quality, information quality, service quality, and attractiveness of the performance dimensions to enhance the performance of the electronic exam system. Meanwhile, alternative A_3 can improve its system quality and service quality dimensions.

5 Conclusion

The electronic exam system performance evaluation process is an important activity for higher education as it can help to increase their overall service's performance and improve their work processes. The performance evaluation process is however complex as it involves multiple selection criteria, and the presence of subjective and imprecise assessments in the decision making process. To ensure effective decision outcomes, it is important to developa structured method capable of comprehensively evaluating the overall performance of available electronic exam systems with respect to the multiple evaluation criteria.

In this paper, we have formulated electronic exam systems' performance evaluation as a fuzzy multicriteria decision making problem, and presented a performance evaluation method for evaluating the performance of electronic exam systems. As an effective alternative to electronic exam systems' performance evaluation, the performance evaluation method developed can effectively handle qualitative performance measures. The empirical study of three electronic exam systems performance evaluation has demonstrated the effectiveness of the method. With its simplicity in concept and computation, the performance evaluation method has general application in dealing with multicriteria performance evaluation problems involving fuzzy assessments of qualitative criteria.

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