



Selection of suitable distance education platforms based on human–computer interaction criteria under fuzzy environment

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Abstract

The rapid spread of the COVID-19 pandemic has affected not only the health industry but also the education sector. E-learning systems have recently become a compulsory part of all education institutions, including schools, colleges, and universities worldwide because of the COVID-19 pandemic crisis. The objectives of the current study were twofold: (1) to conduct an analytical approach for ranking of distance education platforms based on human–computer interaction criteria and (2) to identify the most appropriate distance learning platform for teaching and learning activities by using multi-criteria decision-making approaches. Selection criteria were grouped into human–computer interaction-related criteria, such as ease of use, possibility of causing mental workload, user-friendly interface design, presentation method, and interactivity. In the selection procedure, a spherical fuzzy extension of Analytical Hierarchy Process was utilized to identify the weights of selection criteria and to rank distance education platforms. The results revealed that the most important criterion was *the possibility of causing mental workload* while the most preferable e-learning system was identified as “A3”.

Keywords Fuzzy logic · MCDM · E-learning · Human–computer interaction

1 Introduction

In most countries, as well as in Turkey, educational institutions were closed for the duration of COVID-19, preventing students from continuing their regular studies. Face-to-face education was discontinued as a result of COVID-19 pandemic. Substitute approaches such as distance learning at home were used to ensure uninterrupted instruction. E-learning grew in educational institutions all over the world about 15.4 percent per year without uncertainties or pressures on these institutions and students before the COVID-19 pandemic [1]. However, the situation has changed dramatically, since this study was performed during COVID-19. Recently, Öçal et al. [2] investigated the impact of the COVID-19 pandemic process on classroom instructors' and parents' ICT competencies and experiences. Similarly, Singh et al. [3] assessed the Indian

Government's E-learning Initiatives, particularly during the COVID-19.

E-learning systems have recently become a compulsory part in all institutions of education including schools, colleges and universities around the world because of the COVID-19 pandemic crisis. At the same time, academicians are learning how to use distance education platforms. The transition to online mode, on the other hand, has raised several concerns about educational content [4]. Research by Zaman et al. [5] indicates that distance learning success depends on a variety of variables, such as study modules, user interface and support. Distance learning success regarding the quality of discussions can be improved using the beneficial effects of online participation. However, it is also well known that in an online community not all users are equally active and that there are indeed individuals who never actively participate—the so-called lurkers. Ebner and Holzinger [6] observed that visible interactions do not necessarily indicate learning.

There are more than one distance education platforms which were developed to fulfill the needs of both students and academicians. It is known that time duration while

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looking at screens increased dramatically due to the COVID-19 pandemic. Thus, it becomes more important that the system that is utilized in educational activities does not contribute to the mental workload of academicians.

The objectives of the current study were: (i) to conduct an analytical approach for ranking of distance education platforms based on human–computer interaction criteria and (ii) to identify the most appropriate distance learning platform for teaching and learning activities by using multi-criteria decision-making (MCDM) approaches. The considered selection criteria were grouped into human–computer interaction-related criteria such as ease of use, possibility of causing mental workload, user friendly interface design, presentation method, and interactivity. It is expected that increasing the distance education performances of academicians, getting a higher quality education for students, and developing the interfaces of distance education platforms can contribute to more effective planning of education expenditures.

The rest of this study is organized in the following way. Section 2 provides an overview of the respective subjective literature. The detailed introduction of the usage of MCDM methods is provided in Sect. 3. Section 4 describes the application of the selected MCDM techniques and provides a comparative analysis of the outcomes. In the final section, we provide our findings and recommendations for further research.

2 Background

Despite the fact that e-learning has been evolving for many years, the evaluation of e-learning remains a critical challenge for businesses. The word “evaluation” is used for assessing the importance and value of products by people [7]. According to Tzenget al. [8], the primary goal of e-learning evaluation is to determine a course of action’s effectiveness, efficiency, and appropriateness. The assessment of e-learning helps e-learning administrators and policy makers to distinguish positive and negative behavior, identify errors, correct mistakes, detect risks, and gain optimum investment that allows people to learn effectively [9].

The idea of e-learning is a concept which not only in the practice but also in the literature attracts much interest. MCDM approaches have been performed in the past to choose the best e-learning platform. Alptekin and Karsak [10] provided a decision modeling approach for assessing and addressing the challenge of E-learning product design. Their study’s goal was to boost overall learner satisfaction. To do this, they used Quality Function Deployment (QFD) and fuzzy linear regression to identify appropriate E-learning products. Begičević et al. [11] developed a set

of criteria for evaluating web-based learning. Then, using the AHP approach, they assessed e-learning practices in four stages: intelligence, design, choice, and implementation, and picked the best alternative in the selection stage. Bhuasiri et al. [12] initially identified a number of characteristics that contribute to the effectiveness of E-learning systems in developing nations. They then used AHP with the Delphi technique to analyze the relative relevance of variables across two stakeholder groups, which included ICT professionals and faculty members. Finally, their relevance has been identified and prioritized as essential success criteria.

Using fuzzy preference relations in AHP, the five main criteria for a successful E-learning application and sixteen sub-criteria were identified by Chao and Chen [13] to assess the relative value of these criteria in respect of each other. The primary goal of their research was to improve E-learning practice. AHP approach suggested by Colace et al. [14] to choose the most appropriate e-learning platform in terms of technology and teaching. They concluded that the hierarchy of the structure helps decision-makers to compare different e-learning platform features. Mastalerz [15] presented ELECTRE to address the issue of selecting an appropriate E-learning platform. Similarly, FAHP approach was performed to assess and select a practical and feasible e-learning platform [16]. During this method, a hierarchical model was applied to identify the priorities, criteria, and sub-criteria for selecting an e-learning platform. Yuen [17] suggested the Primitive Cognitive Network Process (P-CNP) as a multi-criteria assessment tool for deciding on the best e-learning platform. The key obstacles to the successful application of existing e-learning projects were poor interface design, inadequate technical support, and lack of IT skills [18]. The three key challenges in e-learning in Kenya include insufficient ICT resources, lack of technological expertise, and financial restrictions [19].

In another study, to assess the quality of E-learning websites, they used an “Axiomatic Design”-based technique for fuzzy group decision making [20]. The findings were then validated using fuzzy TOPSIS approach. Karasan and Erdogan [21] have conducted cognitive mapping extended with intuitionistic fuzzy sets in order to priority the selection factor of the e-learning platform. Infrastructure and ease of use are determined to be the most effective factors based on the results. Recently, a Fuzzy Vikor approach was employed for selecting alternatives among the three learning management systems accepted by colleges in Saudi Arabia [22]. The findings indicate that the most significant factors for decision makers in these organizations are both understandability and time behavior. Karagöz et al. [23] selected suitable learning management systems for organizations by using AHP methods. The

authors used some factors including license cost, flexibility, security and market share for choosing process. Kant et al. [24] applied qualitative design to discuss the features, advantages and attributes of different popular learning management systems. In addition, a questionnaire-based online feedback was used to examine the learners’ and academic counselors’ perspectives. The authors suggest that employing the learning management systems by open and remote learning institutions can provide significant advantages and benefits not only for learners and teachers, but also for the open and remote learning system. Recently, Gong et al. [25] have proposed an integrated MCDM technique based on linguistic hesitant fuzzy sets (LHFSs) and the TODIM (an acronym in Portuguese of interactive and multi-criteria decision making) method to assess and choose the best e-learning website. In addition to these articles, a systematic literature review was conducted by Zare et al. [26], which may be regarded as the primary guide for researchers interested in decision making for e-learning.

Despite the fact that e-learning has been researched for many years, there is a research gap in academicians’ use of e-learning platforms following the COVID-19 outbreak on higher education closure. In this study, unlike the approaches and the main criteria in the literature (Table 1), a different approach was provided for the first time by including academicians’ perspective and human–computer interaction criteria under fuzzy environment. Human–computer interaction helps designers, analysts and users discover system requirements from the design, while usability validates whether the system is effective, safe, easy to learn, easy to remember, easy to use, practical and user friendly [27].

On the basis of human–computer interaction, we determined the five main criteria as ease of use, possibility of causing mental workload, user friendly interface design, presentation method, and group work and interactivity. In the selection procedure, one of the newly developed fuzzy sets, spherical fuzzy sets and spherical fuzzy extension of AHP technique were utilized.

3 Materials and methods

3.1 Spherical fuzzy sets and spherical fuzzy extension of AHP

By combining Pythagorean and Neutrosophic fuzzy sets, Gündoğdu and Kahraman [28] developed and presented spherical fuzzy sets to the literature. Despite the fact that it is a relatively new set, SF sets have rapidly established themselves in the literature and have been included in a variety of MCDM methodologies. By focusing on the

degrees of hesitancy, these sets really help the decision-maker to examine decision-making procedures from a wider viewpoint. In this study, the spherical fuzzy extension of AHP was utilized to select the best e-learning system according to the human–computer interaction basis.

The spherical fuzzy sets (SFS) have membership, non-membership, and hesitancy degree characteristics, much as the Pythagorean fuzzy sets. Let E_1 and E_2 be two universes. Let \tilde{A}_s and \tilde{B}_s of the universe of discourse E_1 and E_2 be as follows:

$$\tilde{A}_s = \{x, (\mu_{\tilde{A}_s}(x), \nu_{\tilde{A}_s}(x), \pi_{\tilde{A}_s}(x)) | x \in E_1\}$$

where $\mu_{\tilde{A}_s}(x) : E_1 \rightarrow [0, 1], \nu_{\tilde{A}_s}(x) : E_1 \rightarrow [0, 1], \pi_{\tilde{A}_s}(x) : E_1 \rightarrow [0, 1]$ and

$$0 \leq \mu_{\tilde{A}_s}^2(x) + \nu_{\tilde{A}_s}^2(x) + \pi_{\tilde{A}_s}^2(x) \leq 1 \quad \forall x \in E_1$$

For each x , $\mu_{\tilde{A}_s}(x)$ shows the membership function, $\nu_{\tilde{A}_s}(x)$ represents the non-membership function, and $\pi_{\tilde{A}_s}(x)$ shows the hesitancy degree.

$$\text{Similarly, } \tilde{B}_s = \{y, (\mu_{\tilde{B}_s}(y), \nu_{\tilde{B}_s}(y), \pi_{\tilde{B}_s}(y)) | y \in E_2\}$$

where $\mu_{\tilde{B}_s}(y) : E_2 \rightarrow [0, 1], \nu_{\tilde{B}_s}(y) : E_2 \rightarrow [0, 1], \pi_{\tilde{B}_s}(y) : E_2 \rightarrow [0, 1]$ and

$$0 \leq \mu_{\tilde{B}_s}^2(y) + \nu_{\tilde{B}_s}^2(y) + \pi_{\tilde{B}_s}^2(y) \leq 1 \quad \forall y \in E_2$$

For each y , $\mu_{\tilde{B}_s}(y)$ shows the membership function, $\nu_{\tilde{B}_s}(y)$ represents the non-membership function, and $\pi_{\tilde{B}_s}(y)$ shows the hesitancy degree [29]. The basic arithmetical operations for the SFS were developed by Gündoğdu and Kahraman [28].

- For summation operation of two SFS, the following formula is presented:

$$\tilde{A}_s \oplus \tilde{B}_s = \left\{ \left(\mu_{\tilde{A}_s}^2 + \mu_{\tilde{B}_s}^2 - \mu_{\tilde{A}_s}^2 \mu_{\tilde{B}_s}^2 \right)^{1/2}, \nu_{\tilde{A}_s} \nu_{\tilde{B}_s}, \left(\left(1 - \mu_{\tilde{B}_s}^2 \right) \pi_{\tilde{A}_s}^2 + \left(1 - \mu_{\tilde{A}_s}^2 \right) \pi_{\tilde{B}_s}^2 - \pi_{\tilde{A}_s}^2 \pi_{\tilde{B}_s}^2 \right)^{1/2} \right\}$$

- For multiplication operation of two SFS, the following formula is presented:

$$\tilde{A}_s \otimes \tilde{B}_s = \left\{ \mu_{\tilde{A}_s} \mu_{\tilde{B}_s}, \left(\nu_{\tilde{A}_s}^2 + \nu_{\tilde{B}_s}^2 - \nu_{\tilde{A}_s}^2 \nu_{\tilde{B}_s}^2 \right)^{1/2}, \left(\left(1 - \nu_{\tilde{B}_s}^2 \right) \pi_{\tilde{A}_s}^2 + \left(1 - \nu_{\tilde{A}_s}^2 \right) \pi_{\tilde{B}_s}^2 - \pi_{\tilde{A}_s}^2 \pi_{\tilde{B}_s}^2 \right)^{1/2} \right\}$$

- For multiplication of a SFS by scalar k ($k > 0$), the following formula is presented:

Table 1 Summary of main criteria and methodologies used for E-learning evaluation

| Author | Methodology | Main criteria |
|--------------------------|---|---|
| Begičević et al. [11] | AHP | <ul style="list-style-type: none"> “Strategic readiness for E-learning implementation” “Basic ICT infrastructure for E-learning” “Human resources” “Legal and formal readiness for E-learning implementation” “Specific ICT infrastructure for E-learning” |
| Alptekin and Karsak [10] | QFD and fuzzy linear regression | <ul style="list-style-type: none"> “Customer needs” “E-learning product characteristics” |
| Mastalerz [15] | ELECTRE | <ul style="list-style-type: none"> “System’s cost Technical support” “Personalization Compatibility with other systems” “Reports and statistics” “Accessibility of learning materials” “Evaluation mechanisms” |
| Bhuasiri et al. [12] | Integrated (AHP) | <ul style="list-style-type: none"> “Learners’ characteristics” “Instructors’ characteristics” “Institution and service quality” “Infrastructure and system quality” “Course and information quality” “Extrinsic motivation” |
| Büyükköçkan et al. [20] | Integrated (TOPSIS) | <ul style="list-style-type: none"> “Right and understandable content” “Complete content” “Personalization” “Security” “Navigation Interactivity” “User interface” |
| Karasan and Erdogan [21] | Cognitive mapping extended with intuitionistic fuzzy sets | <ul style="list-style-type: none"> “Ease of use, Ease of exchanging learning with the others, Capability of controlling learning progress, Network infrastructure, Availability of technical support staff, Exam management system, Video and audio streaming, Pricing, Reporting, Access (time and place), Security and privacy, Trialability, Interactivity level” |
| Karagöz et al. [23] | AHP | <ul style="list-style-type: none"> “License cost, Flexibility, Security, Market share” |
| Kant et al. [24] | A questionnaire-based online feedback | <ul style="list-style-type: none"> “Cost, Quality, Usage, Capacity, Budget” |
| Colace et al. [14] | AHP | <ul style="list-style-type: none"> “Management” “Collaborative Approach” “Management of interactive learning objects” “Usability” “Adaptation of learning path” |
| Chao and Chen [13] | FAHP | <ul style="list-style-type: none"> “E-learning material” “Quality of web learning platform” “Synchronous learning” “Learning record” “Self-learning” |
| Liu et al. [16] | FAHP | <ul style="list-style-type: none"> “Knowledge system” “Learning system” “Organizing system” |

Table 1 (continued)

| Author | Methodology | Main criteria |
|--------------------|--|---|
| Yuen [17] | Primitive Cognitive Network Process | “User friendliness” “Knowledge sharing” “Personalization” “System performance” “System extensibility” “Mobility” |
| Ayouni et al. [22] | Fuzzy Vikor | “Functionality, Reliability, Usability, Efficiency” |
| Gong et al. [25] | Integrated (Linguistic hesitant fuzzy TODIM) | “Navigation, Security, User Interface, Personalization, Interactivity” |

$$k * \tilde{A}_s = \left\{ \left(1 - \left(1 - \mu_{\tilde{A}_s}^2 \right)^k \right)^{1/2}, v_{\tilde{A}_s}^k, \left(\left(1 - \mu_{\tilde{A}_s}^2 \right)^k - \left(1 - \mu_{\tilde{A}_s}^2 - \pi_{\tilde{A}_s}^2 \right)^k \right)^{1/2} \right\}$$

3.2 Calculation process of SF-AHP

Saaty [30] presented the AHP approach, which is one the most popular of the various MCDM techniques. The logic of the AHP is based on linear algebra and pairwise comparisons of decision-making process parts. AHP is a hierarchical representation of a decision-making issue. Since the day it was developed, the AHP technique has been utilized in the solution of decision-making problems in many different fields including green ergonomics [31], Industry 4.0 [32], risk assessment [33, 34], weapon selection [35], safety management [36], and equipment selection [37].

The calculation steps in the application part were adapted from Gündoğdu and Kahraman [29], and are presented as follows:

As in every decision-making method, in this method, the boundaries of the decision problem (decision hierarchy) should be determined first. After that, expert or the expert group is asked to evaluate the criteria, if exist sub-criteria and alternatives. In SF-AHP technique, these evaluations are conducted by utilizing the scale given in Table 2.

In order to check the consistency ratio of pairwise comparison matrices by applying the classical calculation way, the score index (as a crisp number) needs to know. To calculate the score index of AMI, VHI, HI, SMI linguistic expressions following equation is utilized:

$$SI = \sqrt{\left| 100 * \left[\left(\mu_{\tilde{A}_s} - \pi_{\tilde{A}_s} \right)^2 - \left(v_{\tilde{A}_s} - \pi_{\tilde{A}_s} \right)^2 \right] \right|} \tag{1}$$

To calculate the score index of ALI, VLI, LI, SLI following equation is utilized:

$$\frac{1}{SI} = \frac{1}{\sqrt{\left| 100 * \left[\left(\mu_{\tilde{A}_s} - \pi_{\tilde{A}_s} \right)^2 - \left(v_{\tilde{A}_s} - \pi_{\tilde{A}_s} \right)^2 \right] \right|}} \tag{2}$$

The conventional consistency calculating stages are used after determining the score index of each element in the pairwise comparison matrices. The acceptable limit for the maximum consistency ratio is 10%. After checking and

Table 2 Linguistic scale for pairwise comparisons

| Linguistic expressions | (μ, ν, π) | Score index (SI) |
|----------------------------------|-----------------|------------------|
| Absolutely more importance (AMI) | (0.9, 0.1, 0.0) | 9 |
| Very high importance(VHI) | (0.8, 0.2, 0.1) | 7 |
| High importance (HI) | (0.7, 0.3, 0.2) | 5 |
| Slightly more importance(SMI) | (0.6, 0.4, 0.3) | 3 |
| Equally importance (EI) | (0.5, 0.4, 0.4) | 1 |
| Slightly low importance (SLI) | (0.4, 0.6, 0.3) | 1/3 |
| Low importance (LI) | (0.3, 0.7, 0.2) | 1/5 |
| Very low importance (VLI) | (0.2, 0.8, 0.1) | 1/7 |
| Absolutely low importance (ALI) | (0.1, 0.9, 0.0) | 1/9 |

ensuring the all pairwise comparison matrix is consistent, fuzzy weights of criteria, sub-criteria and alternatives are computed. The Spherical Weighted Arithmetic Mean (SWAM) operator is employed for this process.

$$SWAM_w(A_{S1}, \dots, A_{Sn}) = w_1A_{S1} + w_2A_{S2} + \dots + w_nA_{Sn}$$

$$= \left\langle \left[1 - \prod_{i=1}^n (1 - \mu_{\tilde{A}_{si}}^2)^{w_i} \right]^{1/2}, \prod_{i=1}^n v_{\tilde{A}_{si}}^{w_i}, \left[\prod_{i=1}^n (1 - \mu_{\tilde{A}_{si}}^2)^{w_i} - \prod_{i=1}^n (1 - \mu_{\tilde{A}_{si}}^2 - \pi_{\tilde{A}_{si}}^2)^{w_i} \right]^{1/2} \right\rangle \quad (3)$$

where $w = 1/n$.

In order to compute global weights of sub-criteria, fuzzy local weights of sub-criteria and global weights of main criteria must be defuzzify with the help of following equation:

$$S(\tilde{w}_j^s) = \sqrt{\left| 100 * \left[\left(3\mu_{\tilde{A}_s} - \frac{\pi_{\tilde{A}_s}}{2} \right)^2 - \left(\frac{v_{\tilde{A}_s}}{2} - \pi_{\tilde{A}_s} \right)^2 \right] \right|} \quad (4)$$

The calculated crisp weights are normalized by utilizing the following equation:

$$\bar{w}_j^s = \frac{S(\tilde{w}_j^s)}{\sum_{j=1}^n S(\tilde{w}_j^s)} \quad (5)$$

The global weights of the sub-criteria are multiplied by the fuzzy priorities of the alternatives which are calculated with respect to the sub-criteria. This process is conducted by utilizing spherical fuzzy multiplication operator which is presented in the following formula:

$$\tilde{A}_{Sij} = \bar{w}_j^s \cdot A_{Sij}$$

$$= \left\langle \left(1 - (1 - \mu_{\tilde{A}_{si}}^2)^{\bar{w}_j^s} \right)^{1/2}, v_{\tilde{A}_{si}}^{\bar{w}_j^s}, \left((1 - \mu_{\tilde{A}_{si}}^2)^{\bar{w}_j^s} - (1 - \mu_{\tilde{A}_{si}}^2 - \pi_{\tilde{A}_{si}}^2)^{\bar{w}_j^s} \right)^{1/2} \right\rangle \forall i \quad (6)$$

In order to rank the alternatives, the final spherical fuzzy scores of alternatives (\tilde{F}) must be calculated. For each alternative, the following formula applied to find the final fuzzy score of alternatives:

$$\tilde{F} = \sum_{j=1}^n \tilde{A}_{Sij} = \tilde{A}_{S1i} \oplus \tilde{A}_{S2i} \oplus \dots \oplus \tilde{A}_{Sni} \quad \forall i$$

$$\tilde{A}_{S1i} \oplus \tilde{A}_{S12i} = \left\{ \left(\mu_{\tilde{A}_{S11}}^2 + \mu_{\tilde{A}_{S12}}^2 - \mu_{\tilde{A}_{S11}}^2 \mu_{\tilde{A}_{S12}}^2 \right)^{1/2}, v_{\tilde{A}_{S11}} v_{\tilde{A}_{S12}}, \left(\left(1 - \mu_{\tilde{A}_{S12}}^2 \right) \pi_{\tilde{A}_{S11}}^2 + \left(1 - \mu_{\tilde{A}_{S11}}^2 \right) \pi_{\tilde{A}_{S12}}^2 - \pi_{\tilde{A}_{S11}}^2 \pi_{\tilde{A}_{S12}}^2 \right)^{1/2} \right\} \quad (7)$$

In light of this information, the followed path in this paper is shown in Fig. 1.

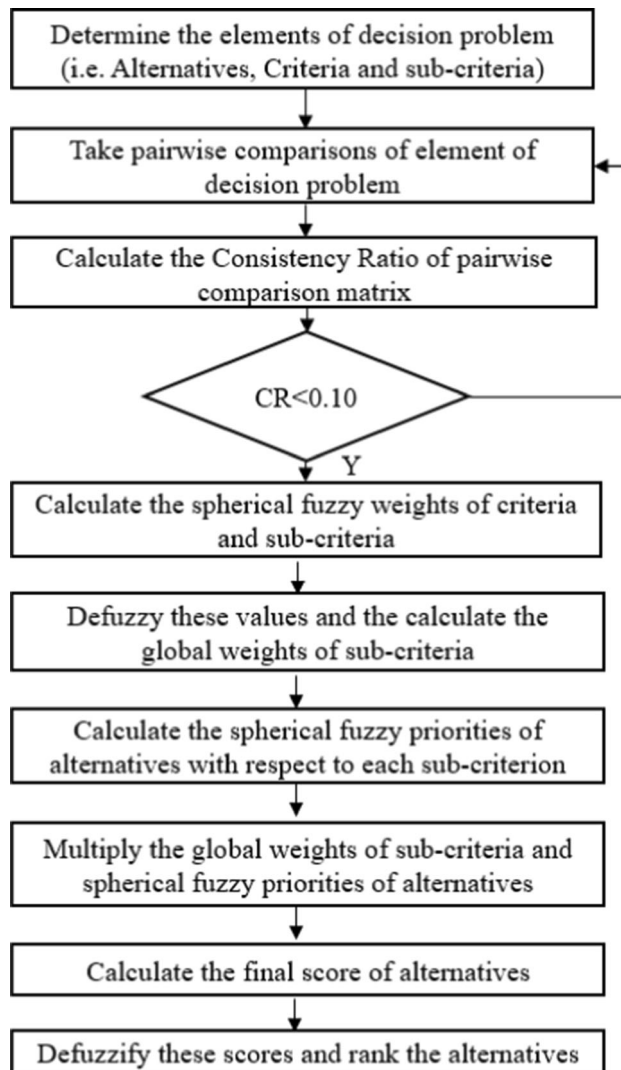


Fig. 1 Study steps for proposed methodology

The calculation steps of the presented SF-AHP method were frequently utilized in the related literature (Gündoğdu and Kahraman [29] (renewable energy); Doğan [38] (mining technology selection); Sharaf [39], Unal and Temur [40] (supplier selection); Kieu et al. [41], Ayyıldız and Gumus [42] (location selection)). Although it is relatively new as a developed technique, it has frequently been used in the literature. Many different applications are available in the literature for further usage in integration with other MCDM techniques.

4 Results and discussion

4.1 Selecting the best e-learning system

In the selection procedure, in addition to the five main criteria and their sub-criteria, the actual names of the

alternative e-learning systems are not given here. They are instead represented by A1, A2, A3, and A4, respectively. Behind the logic of human–computer interaction lies the system requirements for design in every activity related to human–computer interaction [27]. Thus, usability helps in the ergonomic evaluation of any computer-related system in terms of its effectiveness, safety, ease of learning, ease of remembering and use, degree of practical utility, and user-friendliness as the basis of human–machine interaction. The determined criteria and sub-criteria affecting the distance learning system selection on the basis of human–computer interaction are shown in Fig. 2.

First of all, the main and sub-criteria are weighted. Alternatives will then be evaluated on the basis of sub-criteria. As a result, the most suitable alternative will be selected on the basis of these criteria. Table 3 shows linguistic evaluations based on pairwise comparisons of the main criteria that the expert consensus.

The experts utilized the linguistic scale given in Table 2 in the evaluation steps. In total, 7 experts were included in the evaluation. Four of them were academicians using these software packages, and the remaining 3 were people with at least 5 years of experience in the sector. All the presented evaluation matrices were compromised matrices. By following the steps given in the methodology section, firstly the score indexes of the linguistic expressions were calculated by utilizing Eqs. (2) and (3). Then, with the help of the classical consistency index calculation steps, the consistency ratio of the pairwise comparison matrix was conducted. The consistency ratio (CR) was calculated as

Table 3 Pairwise comparison matrix for main criteria

| | C1 | C2 | C3 | C4 | C5 |
|------------|-----|-----|-----|-----|-----|
| C1 | EI | SMI | SMI | HI | VHI |
| C2 | SLI | EI | SMI | HI | AMI |
| C3 | SLI | SLI | EI | HI | HI |
| C4 | LI | LI | LI | EI | SMI |
| C5 | VLI | ALI | LI | SLI | EI |
| CR = 0.090 | | | | | |

Table 4 Spherical fuzzy and defuzzified weights of main criteria

| Main criteria | Spherical Fuzzy weights | Defuzzified weights |
|---------------|-------------------------|---------------------|
| C1 | (0.661, 0.329, 0.262) | 0.250 |
| C2 | (0.691, 0.310, 0.241) | 0.264 |
| C3 | (0.572, 0.419, 0.282) | 0.213 |
| C4 | (0.429, 0.560, 0.286) | 0.155 |
| C5 | (0.338, 0.655, 0.264) | 0.119 |

0.090. The evaluations for the main criteria are consistent because the calculated CR value is less than 0.10. In Table 4, spherical fuzzy weights and defuzzified weights are presented.

In calculating the spherical fuzzy weights of the main criteria, the SWAM operator shown in Eq. (3) was

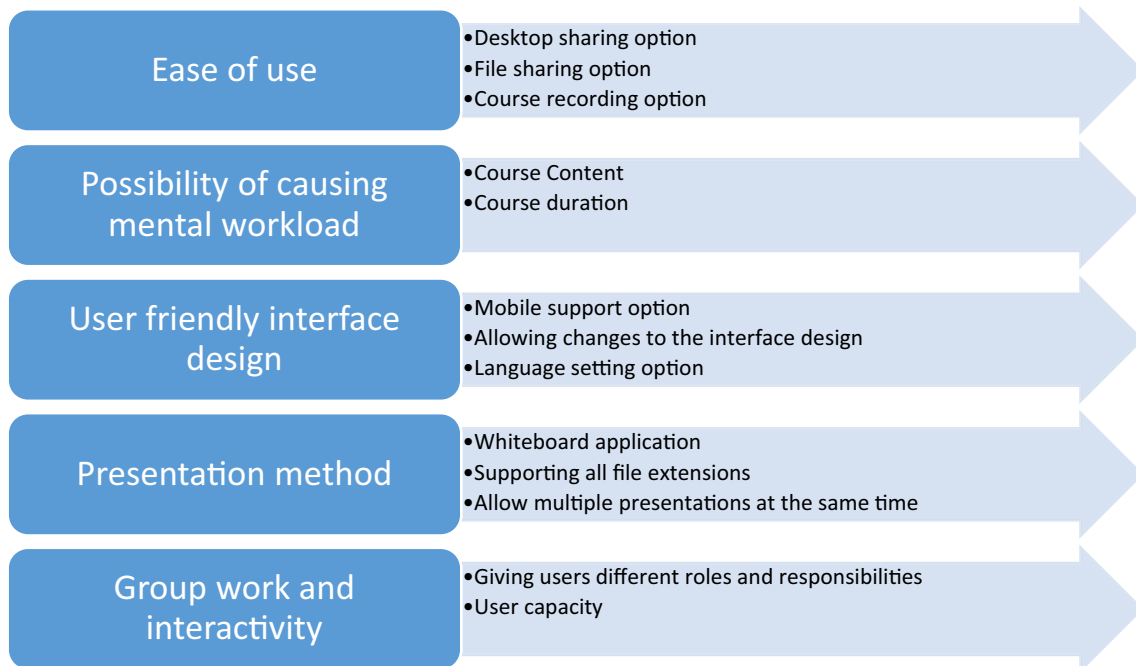


Fig. 2 The determined main and sub-criteria

employed. In the defuzzification process of these spherical fuzzy weights, Eqs. (4) and (5) were utilized, respectively. According to Table 4, the most important selection criterion is determined as C2 that is the possibility of causing workload. After this criterion, the main criterion that affects the selection the most is the ease of use. As seen in the decision hierarchy, each of the main criteria in the problem has sub-criteria. For this reason, the weights of each sub-criterion should be calculated.

Table 5 shows the spherical fuzzy weights of sub-criteria. After calculating the weights of the main and sub-criteria, the global weights of the sub-criteria are calculated. This is the multiplication of the global weights of the main criteria and the local weights of the sub-criteria.

Table 6 presents the local and global weights of sub-criteria. According to Table 6, the most important sub-criteria is determined as C21 that is presentation method. The least important sub-criterion is determined as C42 that is supporting all file extensions. At this stage of the calculation method, the alternatives were evaluated on the basis of sub-criteria. On the basis of each sub-criterion, the alternatives were compared in pairs and the consistency ratios of the comparison matrices were given under each matrix with the abbreviation CR. Fuzzy weights were determined by applying the SWAM operator (Eq. (2)) to

Table 5 Spherical fuzzy and defuzzified weights of sub-criteria

| | Spherical fuzzy weights | Defuzzified weights |
|-----|-------------------------|---------------------|
| C11 | (0.612, 0.363, 0.302) | 0.409 |
| C12 | (0.511, 0.458, 0.338) | 0.331 |
| C13 | (0.411, 0.552, 0.321) | 0.261 |
| | Spherical fuzzy weights | Defuzzified weights |
| C21 | (0.618, 0.346, 0.303) | 0.610 |
| C22 | (0.417, 0.529, 0.331) | 0.390 |
| | Spherical fuzzy weights | Defuzzified weights |
| C31 | (0.695, 0.288, 0.238) | 0.457 |
| C32 | (0.491, 0.482, 0.321) | 0.305 |
| C33 | (0.393, 0.577, 0.311) | 0.238 |
| | Spherical fuzzy weights | Defuzzified weights |
| C41 | (0.666, 0.318, 0.270) | 0.429 |
| C42 | (0.363, 0.607, 0.285) | 0.218 |
| C43 | (0.561, 0.416, 0.304) | 0.353 |
| | Spherical fuzzy weights | Defuzzified weights |
| C51 | (0.554, 0.400, 0.351) | 0.557 |
| C52 | (0.454, 0.490, 0.358) | 0.443 |

Table 6 Local and global weights of sub-criteria

| Main criteria | Sub-criteria | Local weights | Global weights |
|---------------|--------------|---------------|----------------|
| C1 | | 0.250 | |
| | C11 | 0.409 | 0.102 |
| | C12 | 0.331 | 0.083 |
| C2 | C13 | 0.261 | 0.065 |
| | | 0.264 | |
| | C21 | 0.610 | 0.161 |
| C3 | C22 | 0.390 | 0.103 |
| | | 0.213 | |
| | C31 | 0.457 | 0.097 |
| C4 | C32 | 0.305 | 0.065 |
| | C33 | 0.238 | 0.051 |
| | | 0.155 | |
| C5 | C41 | 0.429 | 0.066 |
| | C42 | 0.218 | 0.034 |
| | C43 | 0.353 | 0.055 |
| C5 | | 0.119 | |
| | C51 | 0.557 | 0.066 |
| | C52 | 0.443 | 0.053 |

Bold values are the weights of the main criteria

all these pairwise comparison matrices. These weights are shown in Table 7.

The fuzzy priorities of the alternatives were multiplied by the global weights of the sub-criteria, and the weighted priorities of the alternatives were determined. Equation (6) is utilized in this multiplying process. (The evaluation matrices of alternatives with respect to each sub-criterion are presented in Appendices.)

Table 8 shows the weighted preference relation values of the alternatives. Then, the weighted sums of the alternatives were calculated with Eq. (7). Table 9 shows the final priorities of alternatives and their scores.

Since the priorities obtained are in the fuzzy form, they should be clarified. According to the clarified values, the most suitable distance education alternative on the basis of human–computer interaction was determined as A3.

As can be seen in Table 9, the final score values of the alternatives were calculated very close to each other. For this reason, a basic sensitivity analysis was performed to measure the reaction of the alternatives to the change of criterion weights and to represent the robust results of applied solution. This sensitivity analysis was performed to express more clearly the effect of the criteria on the alternatives and to show how the rankings of alternatives change when the weight of each criterion group is greater than the others. These calculations were made by increasing the weight of the related main criterion by keeping the

Table 7 The spherical fuzzy weights of alternatives with respect to sub-criteria

| | C11 | C12 | C13 | C21 | C22 |
|----|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| A1 | (0.675, 0.313, 0.253) | (0.651, 0.336, 0.277) | (0.713, 0.283, 0.250) | (0.395, 0.583, 0.308) | (0.637, 0.346, 0.277) |
| A2 | (0.534, 0.428, 0.317) | (0.571, 0.412, 0.303) | (0.338, 0.648, 0.265) | (0.658, 0.313, 0.279) | (0.409, 0.563, 0.316) |
| A3 | (0.372, 0.605, 0.289) | (0.528, 0.456, 0.304) | (0.571, 0.412, 0.303) | (0.454, 0.529, 0.300) | (0.536, 0.443, 0.328) |
| A4 | (0.508, 0.443, 0.355) | (0.348, 0.629, 0.268) | (0.528, 0.456, 0.304) | (0.588, 0.372, 0.327) | (0.471, 0.509, 0.316) |
| | C31 | C32 | C33 | C41 | C42 |
| A1 | (0.500, 0.400, 0.400) | (0.387, 0.586, 0.299) | (0.348, 0.629, 0.268) | (0.372, 0.605, 0.289) | (0.554, 0.400, 0.351) |
| A2 | (0.500, 0.400, 0.400) | (0.471, 0.509, 0.316) | (0.651, 0.336, 0.277) | (0.603, 0.383, 0.278) | (0.632, 0.336, 0.302) |
| A3 | (0.500, 0.400, 0.400) | (0.571, 0.412, 0.303) | (0.571, 0.412, 0.303) | (0.708, 0.283, 0.230) | (0.454, 0.490, 0.358) |
| A4 | (0.500, 0.400, 0.400) | (0.637, 0.346, 0.277) | (0.528, 0.456, 0.304) | (0.442, 0.547, 0.292) | (0.423, 0.526, 0.339) |
| | C43 | C51 | C52 | | |
| A1 | (0.536, 0.443, 0.328) | (0.471, 0.509, 0.316) | (0.436, 0.509, 0.346) | | |
| A2 | (0.471, 0.509, 0.316) | (0.409, 0.563, 0.316) | (0.417, 0.529, 0.331) | | |
| A3 | (0.637, 0.346, 0.277) | (0.637, 0.346, 0.277) | (0.609, 0.372, 0.302) | | |
| A4 | (0.409, 0.563, 0.316) | (0.536, 0.443, 0.328) | (0.603, 0.383, 0.278) | | |

Table 8 The weighted preference relation values of the alternatives

| | C11 | C12 | C13 | C21 | C22 |
|----|--------------------|--------------------|--------------------|--------------------|--------------------|
| A1 | (0.25, 0.89, 0.11) | (0.21, 0.91, 0.11) | (0.21, 0.92, 0.09) | (0.16, 0.92, 0.14) | (0.23, 0.90, 0.12) |
| A2 | (0.18, 0.92, 0.12) | (0.18, 0.93, 0.11) | (0.09, 0.97, 0.07) | (0.30, 0.83, 0.15) | (0.14, 0.94, 0.11) |
| A3 | (0.12, 0.95, 0.10) | (0.16, 0.94, 0.10) | (0.16, 0.94, 0.10) | (0.19, 0.90, 0.14) | (0.18, 0.92, 0.13) |
| A4 | (0.17, 0.92, 0.14) | (0.10, 0.96, 0.08) | (0.15, 0.95, 0.09) | (0.26, 0.85, 0.16) | (0.16, 0.93, 0.12) |
| | C31 | C32 | C33 | C41 | C42 |
| A1 | (0.17, 0.91, 0.15) | (0.10, 0.97, 0.08) | (0.08, 0.98, 0.07) | (0.10, 0.97, 0.08) | (0.11, 0.97, 0.08) |
| A2 | (0.17, 0.91, 0.15) | (0.13, 0.96, 0.09) | (0.17, 0.95, 0.08) | (0.17, 0.94, 0.09) | (0.13, 0.96, 0.07) |
| A3 | (0.17, 0.91, 0.15) | (0.16, 0.94, 0.10) | (0.14, 0.96, 0.09) | (0.21, 0.92, 0.08) | (0.09, 0.98, 0.08) |
| A4 | (0.17, 0.91, 0.15) | (0.18, 0.93, 0.09) | (0.13, 0.96, 0.08) | (0.12, 0.96, 0.09) | (0.08, 0.98, 0.07) |
| | C43 | C51 | C52 | | |
| A1 | (0.14, 0.96, 0.09) | (0.13, 0.96, 0.09) | (0.11, 0.97, 0.09) | | |
| A2 | (0.12, 0.96, 0.09) | (0.11, 0.96, 0.09) | (0.10, 0.97, 0.09) | | |
| A3 | (0.17, 0.94, 0.09) | (0.18, 0.93, 0.09) | (0.16, 0.95, 0.09) | | |
| A4 | (0.10, 0.97, 0.08) | (0.15, 0.95, 0.10) | (0.15, 0.95, 0.08) | | |

local weights of the sub-criteria constant, and recalculating the global weights of each sub-criterion. In order to clearly show the effect of the criteria on the ranking of alternatives, the weight of the C1 criterion was taken as 0.90 (in this case the weights of remain criteria should be as follows: C2 = 0.025, C3 = 0.025, C4 = 0.025, C5 = 0.025), and the global weights of the sub-criteria were determined according to these values and the final scores of the alternatives were calculated. Then, the weight of the C2 criterion was taken as 0.90 (in this case the weights of remain criteria should be as follows: C1 = 0.025, C3 = 0.025,

C4 = 0.025, C5 = 0.025) and the final scores of the alternatives were obtained by repeating the same calculations. Similarly, the weights of C3, C4, and C5 criteria were taken as 0.90 and the rankings of the alternatives were recalculated respectively. The result of this calculation is shown in Table 10 and Fig. 3.

The obtained ranking according to the evaluations of the experts was as follows: A3-A1-A2-A4. In this ranking, the score values of the alternatives were determined to be quite close to each other. In the sensitivity analysis for the C4 and C5 criteria of the A3 alternative, it was ranked in the

first place. According to the conducted analysis for the C1 and C3 criteria, the A3 alternative took the second place. Obviously, it is normal to obtain different rankings for different criteria. According to the obtained results, the applied methodology in this study produced robust results.

The main difference of this study from other studies in the literature is that it deals with the selection procedure to be applied in distance learning systems on the basis of human–computer interaction, that is, cognitive ergonomics. In this study, the AHP method was utilized, as is the general trend in the literature [12, 14, 16]. However, in this paper, the AHP method combined with spherical fuzzy sets, which is a newly developed set, was employed because it offers an effective calculation procedure by focusing on the hesitation degree of decision-makers [28]. Therefore, this paper differs from the studies in the literature in terms of both the handled criteria and sub-criteria sets and the utilized solution method.

5 Conclusions

With the concept of distance education rapidly taking hold across all education levels, the popularity of the platforms that provide these services has increased. In this study, distance learning platforms, which are more frequently used, especially with respect to the COVID-19 pandemic, are discussed from the viewpoint of human–computer interactions. Based on pandemic-associated effects, a phenomenon called digitalization in education has emerged, in which educators and students conduct educational activities through digital channels. At this point, educational institutions should choose and utilize one of

Table 9 Final priorities of alternatives and their scores

| Alternatives | Spherical fuzzy priorities | Score index |
|--------------|----------------------------|-------------|
| A1 | (0.54, 0.44, 0.31) | 14.71 |
| A2 | (0.53, 0.45, 0.31) | 14.45 |
| A3 | (0.54, 0.43, 0.31) | 14.73 |
| A4 | (0.52, 0.45, 0.32) | 14.12 |

Table 10 Reacts of alternative rankings according to the criterion weight change

| Alternatives | Highly important criterion = C1 | Highly important criterion = C2 | Highly important criterion = C3 | Highly important criterion = C4 | Highly important criterion = C5 |
|--------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| A1 | 18.53 | 13.95 | 11.73 | 13.00 | 12.32 |
| A2 | 13.80 | 15.78 | 14.27 | 15.45 | 11.26 |
| A3 | 14.92 | 13.44 | 14.57 | 17.62 | 17.08 |
| A4 | 12.69 | 14.66 | 14.76 | 11.62 | 15.29 |
| Ranking | (A1-A3-A2-A1) | (A2-A4-A1-A3) | (A4-A3-A2-A1) | (A3-A2-A1-A4) | (A3-A4-A1-A2) |

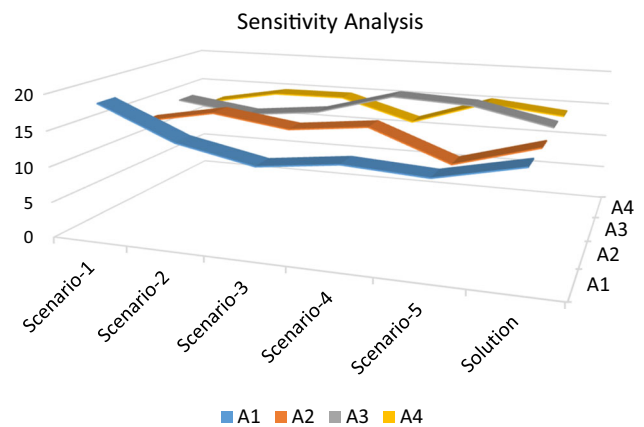


Fig. 3 Sensitivity analysis

the distance learning platforms on the market at almost every stage of education. Because these programs will have a very intense use case for trainers, considering this selection problem in terms of human–computer interaction distinguishes this study from other studies in the literature. The fuzzy scale utilized in this study has never been used in the selection of distance education platforms before. According to the obtained results, Program A3 stood out among the other three alternatives. The criteria that affected this selection are those that are important in terms of human–computer interaction. These include, among others, ease of use and contribution to mental workload. This study also aimed to enable the educational institutions that will make such a choice in practice to do so more easily. In future studies, it may be possible to expand the criteria and alternative sets by considering different characteristics of the selection problems and using different fuzzy scales. Moreover, it is possible to utilize different MCDM techniques by integrating them.

Appendices

| | | | | | | | | | |
|-------------|-----|-----|-----|-----|-------------|-----|-----|-----|-----|
| C11 | A1 | A2 | A3 | A4 | C32 | A1 | A2 | A3 | A4 |
| A1 | EI | HI | VHI | SMI | A1 | EI | SLI | LI | LI |
| A2 | LI | EI | HI | EI | A2 | SMI | EI | SLI | LI |
| A3 | VLI | LI | EI | SLI | A3 | HI | SMI | EI | SLI |
| A4 | SLI | EI | SMI | EI | A4 | HI | HI | SMI | EI |
| CR = 0.05 | | | | | CR = 0.075 | | | | |
| C12 | A1 | A2 | A3 | A4 | C33 | A1 | A2 | A3 | A4 |
| A1 | EI | SMI | SMI | VHI | A1 | EI | VLI | LI | LI |
| A2 | SLI | EI | SMI | HI | A2 | VHI | EI | SMI | SMI |
| A3 | SLI | SLI | EI | HI | A3 | HI | SLI | EI | SMI |
| A4 | VLI | LI | LI | EI | A4 | HI | SLI | SLI | EI |
| CR = 0.087 | | | | | CR = 0.087 | | | | |
| C13 | A1 | A2 | A3 | A4 | C41 | A1 | A2 | A3 | A4 |
| A1 | EI | AMI | SMI | SMI | A1 | EI | LI | VLI | SLI |
| A2 | ALI | EI | LI | LI | A2 | HI | EI | SLI | HI |
| A3 | SLI | HI | EI | SMI | A3 | VHI | SMI | EI | VHI |
| A4 | SLI | HI | SLI | EI | A4 | SMI | LI | VLI | EI |
| CR = 0.071 | | | | | CR = 0.089 | | | | |
| C21 | A1 | A2 | A3 | A4 | C42 | A1 | A2 | A3 | A4 |
| A1 | EI | VLI | SLI | SLI | A1 | EI | EI | SMI | SMI |
| A2 | VHI | EI | HI | EI | A2 | EI | EI | SMI | VHI |
| A3 | SMI | LI | EI | LI | A3 | SLI | SLI | EI | EI |
| A4 | SMI | EI | HI | EI | A4 | SLI | VLI | EI | EI |
| CR = 0.0971 | | | | | CR = 0.0342 | | | | |
| C22 | A1 | A2 | A3 | A4 | C43 | A1 | A2 | A3 | A4 |
| A1 | EI | HI | SMI | HI | A1 | EI | SMI | SLI | SMI |
| A2 | LI | EI | SLI | SLI | A2 | SLI | EI | LI | SMI |
| A3 | SLI | SMI | EI | SMI | A3 | SMI | HI | EI | HI |
| A4 | LI | SMI | SLI | EI | A4 | SLI | SLI | LI | EI |
| CR = 0.0765 | | | | | CR = 0.0765 | | | | |
| C31 | A1 | A2 | A3 | A4 | C51 | A1 | A2 | A3 | A4 |
| A1 | EI | EI | EI | EI | A1 | EI | SMI | LI | SLI |
| A2 | EI | EI | EI | EI | A2 | SLI | EI | LI | SLI |
| A3 | EI | EI | EI | EI | A3 | HI | HI | EI | SMI |
| A4 | EI | EI | EI | EI | A4 | SMI | SMI | SLI | EI |
| | | | | | CR = 0.0765 | | | | |
| C52 | | A1 | | A2 | | A3 | | A4 | |
| A1 | | EI | | EI | | SLI | | LI | |
| A2 | | EI | | EI | | LI | | LI | |
| A3 | | SMI | | HI | | EI | | SMI | |
| A4 | | HI | | HI | | SLI | | EI | |
| CR = 0.099 | | | | | | | | | |

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

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