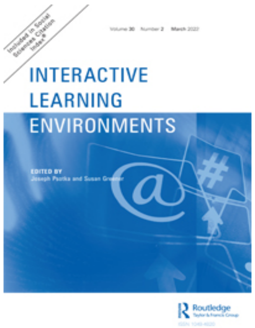


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# Prioritizing the components of e-learning systems by using fuzzy DEMATEL and ANP

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# Prioritizing the components of e-learning systems by using fuzzy DEMATEL and ANP

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**ABSTRACT**

Institutions and universities have started using e–learning systems to reach the potential students from all over the world by decreasing costs of investments. The speed of technological developments increases the importance of e–learning systems and their technology–based components. E–learning systems also decrease the costs of both institutions and students with effective learning way. But, the main problem of e–learning systems is that investment to the right and demanded components is important to actualize cost benefits. The main aim of this study is to analyze the relations of the components of e-learning systems and prioritize them in detail for stakeholders. To solve this problem in this study, causal relations among the components are analyzed by using fuzzy DEMATEL. After determining the causal relations, importance and priorities of the components are calculated according to these relations with the help of fuzzy analytic network process. The application includes 19 components of e–learning systems under three main cluster as e–learning, education and technology. The results of this study supports that the most important components of e–learning systems are technology–based components and these are also the most affected and affecting components of the e-learning systems.

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E-learning; distance learning; fuzzy systems; DEMATEL; ANP

## Introduction

The main problem of today's e-learning systems is technological gap between digital natives and digital immigrants. Brooks and Davis (2018) is also emphasizes that one of the biggest problems of education today is the digital immigrants teaching the digital natives. According to Kesharwani (2019), digital immigrants born before the 1980s, or before the existence of digital technology; digital natives born after the 1980s and exposed to these digital technologies at a very early stage of their lives. Transformations of information and communication technologies has affected the teaching-learning process for digital natives and digital immigrants who use different technological languages (Islas-Pérez, Pérez, Pérez-Ramírez, García-Hernández, & Pérez, 2018). With the increasing importance of e-learning systems and their technologies, digital gap between digital immigrants and digital natives in e-learning systems are becoming more visible and meaningful. Considering the speed of technological developments, this gap and its importance will increase intensely. Because of this and technological qualifications of e-learning systems, components and their importance are totally different than formal learning systems. According to the literature and the results of this study, technological infrastructure and some other technological components are more important than instructor characteristics, course content and education program content for digital natives. Based on this awareness, the main aim of this study is to analyze the relations of the components of

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e-learning systems and prioritize them in detail for the institutions and investors. Almost none of the articles in the literature listed and explained in the second section has analyzed especially technological components and their importance by comparing the other components in e-learning systems.

In this study, prioritizing the components of e-learning is executed. With this aim, the designation of this study is as follows. In Section 2, detailed literature review mainly related with factors and components of e-learning is given. In Section 3, fuzzy DEMATEL is given and fuzzy ANP is given in Section 4. Section 5 is allocated to explain the proposed approach. In Section 6, analyzing the components of e-learning is given in detail. The results obtained in this study is discussed and compared with the previous similar studies in Section 7 and finally, conclusions of the study are given in Section 8.

## The literature review

In this section, detailed literature review related with the factors and components is given. After the detailed literature reviews, it is observed that the e-learning studies gain an increasing importance with 2000s. Especially because of these and the technological needs of e-learning systems, the detailed literature review is started from 2000. A critique on current literature and this study are also given at the end of the section.

Because of the structure of e–learning, most of the studies evaluated the technological components and needs of e-learning systems. As in every web-based system, users' acceptance is one of the most important part of e-learning systems. Liu, Liao, and Peng (2005) proposed an integrated theoretical framework for users' acceptance behavior in web-based e-learning flow, thinking that e-Learning system users are both system users and learners. Ong and Lai (2006) conducted a survey study based on the technology acceptance model (TAM) in Taiwan. Liaw, Huang, and Chen (2007) asked 30 instructors and 168 university students to answer two separate surveys to explore their perceptions in order to explore the attitudes of instructors and students towards e-learning use. Considering that existing e-learning activity models in information systems does not generally take into account the importance of social existence, Johnson, Hornik, and Salas (2008) have extended previous research by developing an e-learning activity model that adds social presence to other variables. In the study of Liu, Liao, and Pratt (2009), a combination of integrated theory contains TAM, flow theory and media richness theory is used to fully capture the complexity of e-learners and system users. Lee (2010) synthesized the expectation confirmation model (ECM), TAM, the theory of planned behavior (TPB), and the flow theory to hypothesis a theoretical model to explain and predict users' intent to continue using e-learning. According to Pocatilu, Alecu, and Vetrici (2010), cloud computing is the best solution for educational institutions that cannot afford the cost of such investments and they measured the positive effects of cloud computing on e-learning development.

Šumak, HeričKo, & PušNik (2011), in order to synthesize the current knowledge on the adoption of learning technology in 2011, conducted literature on 42 independent articles published in major journals and analyzed quantitative results of research work being conducted. A meta-analysis of the causal impact dimensions among the common TAM related associations has been conducted. Bhuasiri, Xaymoungkhoun, Zo, Rho, and Ciganek (2012) described critical success factors affecting the acceptance of e-learning systems in developing countries. Yuen (2012) proposed the Primitive Cognitive Network Process considering multiple criteria and alternatives to address the selection of the most suitable e-learning platform. Al-Qahtani and Higgins (2013) investigated the relationship between e-learning, blended learning and in-class learning and the success of students. The results of Castillo-Merino and Serradell-López's (2014) study showed that motivation is a fundamental variable that influences the performance of online learners and confirms the importance of this factor and is seen as a hidden variable. The effects of theoretical and institutional factors which influence the adoption of e-learning were examined by Okantey and Addo (2016). Islam (2016) explored the moderating role of perceived compatibility on the relationship between e-learning system use and its outcomes. Al-Samarraie, Teng, Alzahrani, and Alalwan (2017) aimed to determine the key factors affecting the satisfaction of e-learning for students and teachers in the context of higher education. Al–Rahmi et al. (2018) carried out a study to investigate students' adoption process by using structural equation modeling. Mohammed, Kasim, and Shaharanee (2018) proposed the use of AHP and TOPSIS methods for the evaluation of e-learning approaches. Al-Fraihat, Joy, and Sinclair (2018) used TAM for the evaluation of e-learning systems success by using various criteria under 6 dimensions. Khan, Ansari, Siddiquee, and Khan (2019) used proximity indexed value as an MCDM method to select the e-learning websites.

Since there was no research showing whether cultural characteristics of students such as individualism and collectivism play a decisive role in the perceived e-learning success, Aparicio, Bacao, and Oliveira (2016) worked on this area and came to the conclusion that satisfaction for students with stronger individualism cultures plays a central role in evaluating individual effects on individual and organizational influences.

There are many and various criteria in evaluating e-learning effectiveness. There is also a lot of work on evaluating e-learning effectiveness. A Multi Criteria Decision Making (MCDM) model has been proposed by Tzeng, Chiang, and Li (2007) since a generalized quantitative assessment model that considers the interrelated relationship simultaneously, both between the criteria and the blurring of subjective perception, is lack. In the UK West Midlands region, an e-learning study was conducted to assess the educational effectiveness of a clinically integrated e-learning course in postgraduate medical interns compared to traditional course-based courses in seven training hospitals (Hadley et al., 2010). Ho and Dzeng (2010) have tested the effectiveness of safety education to avoid falling education through different learning modes used to assess safety behavior and learning effectiveness throughout the training period. Büyüközkan, Arsenyan, and Ertek (2010) has adopted an axiomatic design for fuzzy group decision-making to assess the quality of e-learning websites. Sridharan, Deng, Kirk, and Corbitt (2010) they have presented a study aiming to empirically test the theoretical (pedagogy, technology and management) (PTM) model of students' preferences, which is an important prerequisite of sustainable e-learning, and the perceived impact of e-learning effectiveness.

Colace and De Santo (2011) proposed a model for the identification, characterization and selection of an e-learning platform in a study they conducted. Mustafa and Sharif (2011) presented an approach to integrating learning styles into adaptive e-learning hypermedia and they aimed to assess the impact of individualized educational materials in adapting to learning styles of students. Sung, Chang, and Yu (2011), introduced e-learning courseware quality assurance system which helped manufacturers improve the quality of e-learning course software, change their design concepts related to e-learning course software, and develop new concepts. Mehregan, Jamporazmey, Hosseinzadeh, and Mehrafrouz (2011) introduced a new fuzzy analytical hierarchy process (FAHP) approach to evaluate the e-learning system by identifying and prioritizing the critical success factors (CSFs) that should be intensified by the universities and educational institutes. Tseng, Lin, and Chen (2011) conducted a study aimed at evaluating the effectiveness of teaching or learning in an e-learning system measures in linguistic preferences. In his study, he showed that the fuzzy analytic networking process is an effective way to identify the primary measures affecting the effectiveness of e-learning. An e-learning course evaluation questionnaire as a valid and reliable measurement model, which can be used to improve individual online courses with the results of the work done was developed by Balaban, Bubas, and Pipan (2011). Nilashi and Janahmadi (2012) defined the important factors which affected on successes in e-learning websites. Syamsuddin's (2012) study aimed to develop a new methodology to evaluate the quality of e-learning software by both qualitative and quantitative analyses. Wang and Lin (2012) combined the Fuzzy Analytic Hierarchy Process and Association Rule after interviews with 30 experts who compared the various criteria for evaluating the process of "Practice Score" and "Interactive Learning". Chuang and Lin (2014) have extensively analyzed the research model with the DEMATEL-based ANP approach, which expresses causal relations between major research constructs and represents relationships in the visual impact association map. Jain, Garg, and Bansal (2015) defined the selection and evaluation of e-learning websites as a multi-criteria decision-making problem. Islas-Pérez et al. (2015) studied benchmark of e-learning tools and defined of a set of criteria of e-learning management systems.

Mohammed, Kasim, AL-Dahneem, and Hamadi (2016) analyzed various aspects of e-learning related applications using the Fuzzy AHP method. They showed that all qualifications are comparable for both e-learning and traditional methods. Zadgari (2016) prepared a study to evaluate the quality of e-learning services. Su, Tzeng, and Hu (2016) applied a new hybrid fuzzy multiple criteria decision-making model to evaluate cloud e-learning strategies. Jain, Garg, Bansal, and Saini (2016) modeled the problem of assessment and selection of e-learning web sites as an MCDM problem and proposed weighted distance-based approximation method for solution. Garg and Jain (2017a) emphasized the development of a hierarchical model using the Fuzzy Multiple Attribute Decision Making method in the selection of e-learning websites. In the same year, Garg and Jain (2017b) published another study by using fuzzy set theory to calculate the priority weights of e-learning website selection criteria.

### *Interpretation of the literature review*

All of the studies in the literature indicates that students play an important role about the designation of the education system. Because of this, almost all of the studies were carried out with students. In an education system, at least 10 year difference exists between students and instructors. This 10 year is not an important difference like generation difference in formal education. Contrariwise, in an e-learning system, 10 year difference is like at least 2 or 3 generation difference between students and instructors. The most important reasons of this are the speed of technological development and its effects on our daily life. Because, when a technology is changed, it also changes our daily routine and language. As Prensky (2001) said, we need to be thinking about how to teach both legacy and future content in the language of the Digital Natives as instructors. Today, while most of the students are Digital Natives, most of the instructors are Digital Immigrants who also always have to update their technological knowledge and its integration with their courses. Hence, communication between Digital Natives and Digital Immigrants is an important subject in e-learning systems. Determining the prioritization and weights of the components of e-learning systems, especially including technological component details, will help to improve this communication level between them. Because of these and according to lack of literature, we aim to prioritize the components of e-learning systems. To achieve this aim, we prefer to use DEMATEL and ANP methods. Literature studies show that DEMATEL method has a high and proved success about determining the relations between components (criteria) and ANP has a high and proved success about determining the importance of them to prioritize them. Other MCDM (Multi Criteria Decision Making) methods were not chosen because of the components which have no relation or effect with most of other components to compare them. And also to observe the relations in a better and clear way without small or big effects of unrelated components.

## Proposed analysis approach

### *Fuzzy DEMATEL*

#### *Formation and bases of fuzzy DEMATEL*

Decision Making Trial and Evaluation Laboratory (DEMATEL) method developed at the Geneva Research Centre of the Battelle Memorial Institute (Gabus & Fontela, 1972) is based on matrix calculations and graph theory. DEMATEL method as a multiple criteria decision making method enables to evaluate and obtain the causal relations among the factors. Besides, it also enables to display the strength of relations and influences among the factors analytically.

Although classical or crisp DEMATEL is very effective in revealing the cause and effect relationships among factors and prioritizing them, it may have some difficulties in describing uncertainty (Bai & Sarkis, 2013). In order to overcome this and increase its effectiveness, various extensions of DEMATEL method have been developed in the recent decade. Almost all of the fuzzy extensions of DEMATEL method is based on triangular fuzzy numbers. A detailed and comprehensive literature for fuzzy extensions of DEMATEL method can be found in the study of Dytczak and Ginda (2013). And other recent fuzzy DEMATEL extensions can be found in the studies of Gigović, Pamučar, Lukić, and Marković (2016a) and Bongo and Ocampo (2017a, 2017b).

For classical and crisp representation of DEMATEL and ANP and their detailed calculation steps and other related applications, recent good studies of Dimić, Pamučar, Ljubojević, and Đorović (2016), Gigović, Pamučar, Bajić, and Milićević (2016b) and Gigović, Pamučar, Božanić, and Ljubojević (2017) can be studied.

## Proposed fuzzy DEMATEL

Computational steps of the fuzzy DEMATEL used in this study are given below.

*Step 1: Defining the evaluation components and determining the fuzzy linguistic scale:* The evaluation components are defined and a fuzzy linguistic scale for better representation of human assessments is determined. The linguistic scale and the corresponding fuzzy numbers used in the DEMATEL calculations are given in Table 1.

*Step 2: Establishing the direct relation matrix:* To display and evaluate the relationship between components shown as $C = \{C_i | i = 1, 2, \ldots, n\}$, pairwise comparisons according to Table 1 are done by a group of experts. The initial direct relation fuzzy matrix $Z^k$ is obtained as shown in Equation (1).

$$Z^k = \begin{bmatrix} 0 & \tilde{z}_{12}^k & \tilde{z}_{13}^k & \cdots & \tilde{z}_{1j}^k & \cdots & \tilde{z}_{1n}^k \\ \tilde{z}_{21}^k & 0 & \tilde{z}_{23}^k & \cdots & \tilde{z}_{2j}^k & \cdots & \tilde{z}_{2n}^k \\ \tilde{z}_{31}^k & \tilde{z}_{32}^k & 0 & \cdots & \tilde{z}_{3j}^k & \cdots & \tilde{z}_{3n}^k \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{z}_{i1}^k & \tilde{z}_{i2}^k & \tilde{z}_{i3}^k & \cdots & \tilde{z}_{ij}^k & \cdots & \tilde{z}_{in}^k \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1}^k & \tilde{z}_{n2}^k & \tilde{z}_{n3}^k & \cdots & \tilde{z}_{nj}^k & \cdots & 0 \end{bmatrix} \tag{1}$$

where $k$ is the number of experts and $\tilde{z}_{ij}^k = (\tilde{z}_{ij(1)}, \tilde{z}_{ij(2)}, \tilde{z}_{ij(3)})$ the fuzzy intensity of influence of cluster $i$ on cluster $j$ according to the expert $k$ and $\tilde{z}_{ii}^k = (0, 0, 0)$ for i = 1, 2, .., n.

*Step 3: Combining all fuzzy direct relation matrices:* All of the fuzzy direct relation matrices are averaged and aggregated matrix Z is obtained as shown in Equation (2).

$$Z = \frac{\left(\sum_{i=1}^{k} Z^k\right)}{k} \tag{2}$$

*Step 4: Establishing and analyzing the structural model:* To transform the components scales into comparable scales, the linear scale transformation is changed to a normalization formula. Let

$$\sum_{j=1}^{n} \tilde{z}_{ij} = \left(\sum_{j=1}^{n} z_{ij(1)}, \sum_{j=1}^{n} z_{ij(2)}, \sum_{j=1}^{n} z_{ij(3)}\right) \tag{3}$$

and $r = \max_{1 \le i \le n}\left(\sum_{j=1}^{n} z_{ij(3)}\right)$

**Table 1.** Linguistic scale and fuzzy number representation for Fuzzy DEMATEL.

| Crisp value | Linguistic term | Fuzzy number |
|---|---|---|
| 4 | Very High Influence (VH) | (0.75, 1, 1) |
| 3 | High Influence (H) | (0.50, 0.75, 1) |
| 2 | Low Influence (L) | (0.25, 0.50, 0.75) |
| 1 | Very Low Influence (VL) | (0, 0.25, 0.50) |
| 0 | No Influence (NI) | (0, 0, 0.25) |

Then, the fuzzy normalized direct-relation matrix, G, is equal to $G = r^{-1} \cdot Z$, where $\tilde{g}_{ij} = (\tilde{z}_{ij}/r) = (z_{ij(1)}/r, z_{ij(2)}/r, z_{ij(3)}/r)$.

*Step 5: Establishing the total relation matrix:* After obtaining the fuzzy normalized direct relation matrix G, the fuzzy total relation matrix $T_f$ can be calculated by using $T_f = G(I - G)^{-1}$, where $\tilde{t}_{ij} = (t_{ij(1)}, t_{ij(2)}, t_{ij(3)})$.

*Step 6: Defuzzification and calculating the sum of rows and columns:* Before calculating the sum of rows and columns, the fuzzy total relation matrix $T_f$ is defuzzified. The fuzzy numbers are converted into crisp values by modified CFCS (Converting Fuzzy data into Crisp Scores) method (Wu & Lee, 2007) given below.

$$t_{ij(1)} = \frac{t_{ij(1)} - \min_i(t_{ij(1)})}{\Delta_{\min}^{\max}} \tag{4}$$

$$t_{ij(2)} = \frac{t_{ij(2)} - \min_i(t_{ij(1)})}{\Delta_{\min}^{\max}} \tag{5}$$

$$t_{ij(3)} = \frac{t_{ij(3)} - \min_i(t_{ij(1)})}{\Delta_{\min}^{\max}} \tag{6}$$

where $\Delta_{\min}^{\max} = \max(t_{ij(3)}) - \min(t_{ij(1)})$

$$t_{ij(1)} = \frac{t_{ij(2)}}{1 + t_{ij(2)} - t_{ij(1)}} \tag{7}$$

$$t_{ij(3)} = \frac{t_{ij(3)}}{1 + t_{ij(3)} - t_{ij(2)}} \tag{8}$$

Finally, defuzzified total relation matrix $T = [t_{ij}]_{n\times n}$ is obtained by using the following equations:

$$t'_{ij} = \frac{t_{ij(1)}(1 - t_{ij(1)}) + t_{ij(3)}t_{ij(3)}}{1 - t_{ij(1)} + t_{ij(3)}} \tag{9}$$

$$t_{ij} = \min_j (t_{ij(1)}) + t'_{ij}\Delta_{\min}^{\max} \tag{10}$$

After that, d and r values, which are the sum of rows and columns respectively, are calculated by using the total relation matrix T.

$$T = [t_{ij}], \quad i, j \in \{1, 2, \ldots, n\}$$

$$\begin{aligned} d = (d_i)_{n\times 1} &= \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \\ r = (r_j)_{1\times n} &= \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} \end{aligned} \tag{11}$$

*Step 7: Analyzing the results:* Sum of $d$ and $r$ values $(d + r)$ represents the effects among components and difference of d and r values $(d - r)$ represents the causal relations among components. Namely, $(d + r)$ shows the importance of components and $(d - r)$ represents the effects. If a $(d - r)$ value of a component is positive, that component has a cause effect on the other components, and if a $(d - r)$ value of a component is negative, that component is affected by the other components. Besides, a threshold value must be determined to construct the network structure among components. The arithmetic mean is generally chosen as a threshold value in the literature. But, it can be also chosen lower or higher than the arithmetic mean according to the expert opinions about the problem.

## Fuzzy ANP

### Formation and bases of fuzzy ANP

ANP which was developed by Saaty (1996) mainly focuses on how to solve decision problems with uncertainty and with multiple criteria characteristics by decomposing a complex MCDM problem. ANP incorporates the evaluations of all decision makers into a final decision by pairwise comparisons of alternatives. The ANP is a comprehensive decision making technique that captures the outcome of dependence and feedback within and between clusters of elements and permits complex inter-relationships among decision levels and attributes. Fuzzy ANP is an extension of crisp ANP in which fuzzy numbers are incorporated with the pairwise comparisons to model the uncertainty in human judgment and preference.

### Proposed fuzzy ANP

Computational steps of the fuzzy based ANP applied in this study are given below.

*Step 1: Defining the problem:* In this step; a goal, components, sub- components and alternatives are defined. After defining inner and outer dependencies among the problem, elements are identified in detail. With these determinations, the feedback network structure of the problem is constructed.

*Step 2: Determining the fuzzy linguistic scale and making the pairwise comparisons:* The linguistic scale and the corresponding fuzzy numbers for fuzzy ANP are given in Table 2.

Pairwise comparisons in ANP are performed as in AHP method. Making the pairwise comparisons among the components, sub- components and alternatives which influence each other is the difference between AHP and ANP. The pairwise comparisons are obtained like the matrix given below.

$$A_f^d = \begin{bmatrix} \tilde{a}_{11}^d & \tilde{a}_{12}^d & \cdots & \tilde{a}_{1j}^d & \cdots & \tilde{a}_{1n}^d \\ \tilde{a}_{21}^d & \tilde{a}_{22}^d & \cdots & \tilde{a}_{2j}^d & \cdots & \tilde{a}_{2n}^d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{a}_{i1}^d & \tilde{a}_{i2}^d & \cdots & \tilde{a}_{ij}^d & \cdots & \tilde{a}_{in}^d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1}^d & \tilde{a}_{n2}^d & \cdots & \tilde{a}_{nj}^d & \cdots & \tilde{a}_{nn}^d \end{bmatrix} \quad (12)$$

where $d$ is the number of experts and $\tilde{a}_{ij}^d = (\tilde{a}_{ij(1)}^d, \tilde{a}_{ij(2)}^d, \tilde{a}_{ij(3)}^d)$, $i, j \in \{1, 2, \ldots, n\}$ are fuzzy numbers. The $\tilde{a}_{ji}^d = (1/\tilde{a}_{ij(3)}^d, 1/\tilde{a}_{ij(2)}^d, 1/\tilde{a}_{ij(1)}^d)$ formulation is provided between the components of the matrix $A_f^d$.

*Step 3: Combining all pairwise comparisons:* All pairwise comparisons are averaged by using geometric mean formulation, $\tilde{a}_{ij} = \sqrt[D]{\prod \tilde{a}_{ij}^d}$ and the aggregate pairwise comparisons matrix $A_f = [\tilde{a}_{ij}]$ is obtained.

*Step 4: Defuzzification of the fuzzy pairwise comparisons:* The weights are obtained by solving the Equation (22) (Saaty, 1980).

$$AW = \lambda_{\max} W \quad (13)$$

**Table 2.** Linguistic scale and fuzzy number representation for Fuzzy ANP.

| Crisp value | Linguistic term | Fuzzy number |
|---|---|---|
| 1 | Equally Important (EI) | (1,1,2) |
| 3 | Weakly Important (WI) | (2,3,4) |
| 5 | Important (I) | (4,5,6) |
| 7 | Strongly Important (SI) | (6,7,8) |
| 9 | Absolutely Important (AI) | (8,9,9) |

In Equation (13), A is the pairwise comparison matrix, W is the vector of the weights and $\lambda_{max}$ is the largest eigenvalue of matrix A. In Equation (13), matrix A consists of crisp values, so before the calculation of this part, matrix $A_f$ is defuzzified. The fuzzy numbers are converted into crisp values ($A = [a_{ij}],\ \ i, j \in \{1,\ 2,\ \ldots, n\}$) by modified CFCS method given in Equations (4)–(10).

*Step 5: Generating the supermatrix:* Supermatrix includes inner matrices which represent the dominances between clusters. The general form of a supermatrix of a network is explained and given by Saaty (1996). In the supermatrix, weights represent the relative dominances of clusters and if there is no influence between two clusters, relative dominance weight is zero.

*Step 6: Calculating the limit supermatrix and the global weights:* Before calculating the limit supermatrix, each element of the column is divided by the sum of the column that contains the element for normalization. Sum of each column equals to 1 after the calculations for normalization. Then, the limit supermatrix is calculated with Equation (14) using the normalized supermatrix.

$$\lim_{k \to \infty} W^k \tag{14}$$

All of the column vectors are same in this limit supermatrix. With the normalization of the limit supermatrix, the global weights of all elements are obtained and also the sum of the global weights equals to 1.

## All application steps of the proposed approach

In this proposed approach, components of e-learning systems are analyzed with fuzzy DEMATEL and fuzzy ANP. Fuzzy linguistic scales are used in all processes for better representation of human assessments. Fuzzy DEMATEL method is used to determine the structure of the relationships and effects among the components of e-learning systems. Then, the weights of the evaluation components of e-learning systems are calculated with fuzzy ANP using the information which is obtained from fuzzy DEMATEL according to the pairwise comparisons of the e-learning students. Figure 1 displays the framework of the proposed fuzzy based multi criteria decision making approach as a flowchart. The flowchart is designed by considering the methodology and the research problem to make the connection between them.

## Analyzing the components of e-learning systems with the proposed approach

### *Bases of the analysis and components*

The application of the proposed fuzzy multi-criteria decision making approach is for the analysis of the components of e-learning systems under subjective perspective with linguistic scales. The most of the studies in the literature related with ANP and DEMATEL methods, pairwise comparisons are done by only one expert like the studies of Tadić, Zečević, and Krstić (2014), Büyüközkan and Çifçi (2012) and Mohanty, Agarwal, Choudhury, and Tiwari (2005), and also for the other papers, pairwise comparisons are done by up to 10 experts like the studies of Dargi, Anjomshoae, Galankashi, Memari, and Tap (2014), Sevkli et al. (2012) and Kang, Lee, and Yang (2012). Computational difficulties of multiple pairwise comparisons are the most important reason of making small number of pairwise comparison of experts. This can cause subjectivity of the analysis. To overcome this situation, a simple computation algorithm was coded with java and pairwise comparisons of 37 experts (students in this study) were included in the system. Thus, complex calculations could be done easily and without any human error. As Bajpai, Sachdeva, and Gupta (2010) mentioned, fuzzy set theory is used to handle for subjectivity and uncertainty associated with the data and reduces the subjectivity. The components, which are given in Table 3 were determined after literature review from the databases (Google Scholar, Web of Science, Science Direct and EbscoHost) and discussions with the experts on e-learning systems, were applied to 37 students from different e-learning programs in

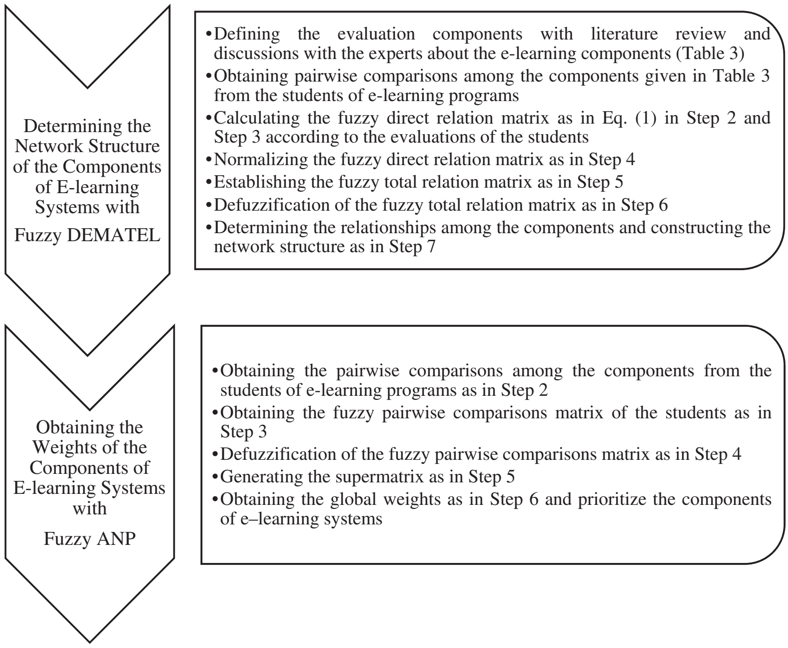


**Figure 1.** Framework of the proposed fuzzy multi-criteria decision making approach.

various countries in Europe. The experts helped for the important components of e-learning systems in this study have been studying on e-learning systems for years and working as professors at research-intensive universities in departments directly related with education.

37 students between 23 and 28 years old, who have been receiving education at least 2 years through official e-learning systems of universities, are chosen from MSc and PhD students especially for the representation of the systems and evaluations in the best way. BSc degrees of the students are from different social, natural and engineering sciences programs of different universities in Europe. Besides of this, another reason of selecting the students is that they have knowledge about the numerical representations and the method for the qualification of the pairwise comparisons with their MSc or PhD degrees. Thus, evaluations can be obtained with the students qualifiedly and eligibly for the analysis.

The components, which are included and explained in a study in the literature, are shown next to it with the name of the study in Table 3 for a detailed review of the relevant people. The experts helped in this study are working at some different European universities. They are working in various e-learning systems as instructors who can also observe the system better, and their areas of expertise are also e-learning and distance learning. The students are selected to observe the components of e-learning systems through their perspectives. In an education system, especially if it is a technology-based system, students play an important role to the design of the education system. This is an important subject for e-learning systems in today's world, especially because of the generation differences of instructors and students. Prensky (2001) mentioned that we need to be thinking about how to teach both legacy and future content in the language of the Digital Natives as instructors. Today, while most of the students are Digital Natives, most of the instructors are Digital Immigrants. Hence, communication between Digital Natives and Digital Immigrants is an important subject in e-learning systems. Determining the prioritization and weights of the components of e-learning systems will help to improve this communication level between them. Pairwise comparisons of the components in the analysis were done by the students because of these reasons. Cost related components are not included in this study to analyze the other main components through students'

**Table 3.** The components of e-learning systems.

| Symbol | Cluster | The name of the component |
|---|---|---|
| TC–1 | Technology | Information Technologies Infrastructure (Soong, Chan, Chua, & Loh, 2001) |
| TC–2 | Technology | User Interface (Shee & Wang, 2008) |
| TC–3 | Technology | System Security (Ozkan & Koseler, 2009) |
| TC–4 | Technology | Technical Support (Soong et al., 2001) |
| TC–5 | Technology | Coordination and Communication (Martínez-Torres, Toral, & Barrero, 2011) |
| TC–6 | Technology | Offline Functionality (Selim, 2007) |
| TC–7 | Technology | Diversity of the Instruments (Papp, 2000) |
| TC–8 | Technology | Data Storage Space (Masud & Huang, 2012) |
| TC–9 | Technology | Student Tracking System (Ozkan & Koseler, 2009) |
| TC–10 | Technology | Interactivity (Martínez-Torres et al., 2011) |
| EC–1 | Education | System Content Update (Shee & Wang, 2008) |
| EC–2 | Education | Instructor Characteristics (Mosakhani & Jamporazmey, 2010) |
| EC–3 | Education | Education Program Content (Sun, Tsai, Finger, Chen, & Yeh, 2008) |
| EC–4 | Education | Course Content (Sun et al., 2008) |
| LC–1 | E-learning | Special Programs for People with Disabilities (Fichten et al., 2009) |
| LC–2 | E-learning | The Use of Technology by Instructor (Leidner & Jarvenpaa, 1993) |
| LC–3 | E-learning | The Use of Technology by Students (Volery & Lord, 2000) |
| LC–4 | E-learning | Assessment and Fairness (Ozkan & Koseler, 2009) |
| LC–5 | E-learning | Motivation (Selim, 2007) |

perspective without any cost factor as the price of the e-learning program, price of each course, price of repeat year, etc.

## *Analyzing the network structure among components*

In this part of this study, Fuzzy DEMATEL is applied to construct the structure among the clusters and components of e-learning systems. Table 4 shows the total relation matrix among three clusters which are Technology (TC), Education (EC) and E-Learning (LC). Table 5 shows the causal relations and importance of the clusters. According to Results in Table 5, Technology Components has the greatest d and r values with 32.225 and 29.877 respectively. Education Components has the smallest d and r values with 15.995 and 12.090 respectively. According to $d + r$ results, Technology Components are the most important components. Education Components has the greatest $d - r$ value with 3.905 and Technology Components has 2.348 $d - r$ value. This means that Education Components and Technology Components effect on others and E-learning Components are effected by others with the –6.253 $d - r$ result.

In Appendix A, the results of the total relation matrix among the components of e-learning are shown. A threshold value must be determined to construct the network structure among the components. The arithmetic mean is generally chosen as a threshold value in the literature. The threshold value for the total relation matrix which is given in Appendix A is 0.185 (μ). In Appendix A, the values which are greater than or equal to the threshold value 0.185 are shown as bold.

The detailed causal relations and importance of the components of e-learning systems are shown in Table 6 to observe the results better. Information Technologies (IT) Infrastructure (TC–1) has the greatest $d + r$ value. According to this result, IT Infrastructure is the most important component in an e-learning system and it has also the greatest effect on other components with 5.777 value. Motivation (LC–5) is the most affected component by others with the negative and lowest $d - r$ value which is –4.591.

**Table 4.** The results of total relation matrix among clusters.

| Component Cluster | Technology components | Education components | E-learning components |
|---|---|---|---|
| Technology Components | 14.494 | 12.225 | 5.507 |
| Education Components | 6.783 | 6.512 | 2.701 |
| E-learning Components | 8.601 | 6.200 | 3.883 |

**Table 5.** The causal relations and importance of the clusters.

| Component cluster | $d$ | $r$ | $d+r$ | $d-r$ |
|---|---|---|---|---|
| Technology Components | 32.225 | 29.877 | 62.103 | 2.348 |
| Education Components | 15.995 | 12.090 | 28.086 | 3.905 |
| E-learning Components | 18.683 | 24.937 | 43.620 | −6.253 |

For the detailed network structure of the components, bold values of Appendix A can be checked, which also shows relations and their directions among the components. In Appendix A, row components have an impact on the column components. For example; TC-1 and TC-7 components have effect on one another. And, TC-1 has effect on TC-2 but, TC-2 has no effect on TC-1.

### *Determining the weights of the clusters and components*

After determining the network structure of the components of e-learning with the help of fuzzy DEMATEL, the weights of the components are obtained by using fuzzy ANP. Fuzzy pairwise comparisons among the components were applied to 37 students from different e-learning programs in various countries in Europe. Because of the size of the data set, combined and normalized fuzzy pairwise comparison results for all components could not be given here. Pairwise comparisons of the components according to the scale given in Table 2 are aggregated by using Equation in step 3. After calculating the fuzzy weights of these aggregated fuzzy pairwise comparisons, they are defuzzified and normalized by using Equations (9)–(15) to obtain the values of the columns of defuzzified normalized supermatrix of ANP shown in Appendix B.

After calculating the pairwise comparisons for each criterion and combining the defuzzified results, the normalized supermatrix is obtained as in Appendix B.

Final weights of the components of e-learning systems are calculated by using Equation (14) with the normalized supermatrix shown in Appendix B. Obtained weight results of the components of e-learning systems are shown in Table 7 in detail. Gray ANP (Çelikbilek & Tüysüz, 2016) results are also shown in Table 7 as a validation of the results and ranking.

### *Interpretation of the results and ranking*

In Figure 2, results of the analyses are shown as a pie chart to point to show the importance of the clusters and observe the clusters more clearly. Components of the clusters are ranked by their

**Table 6.** The causal relations and importance of the components of e-learning.

| Component | $d$ | $r$ | $d+r$ | $d-r$ |
|---|---|---|---|---|
| TC–1 | 8.130 | 2.353 | 10.483 | 5.777 |
| TC–2 | 5.073 | 2.147 | 7.220 | 2.927 |
| TC–3 | 1.200 | 1.537 | 2.737 | −0.337 |
| TC–4 | 3.613 | 1.673 | 5.286 | 1.940 |
| TC–5 | 1.515 | 3.743 | 5.258 | −2.228 |
| TC–6 | 1.891 | 2.809 | 4.700 | −0.917 |
| TC–7 | 4.260 | 3.737 | 7.997 | 0.523 |
| TC–8 | 2.260 | 3.726 | 5.986 | −1.466 |
| TC–9 | 0.786 | 2.657 | 3.443 | −1.871 |
| TC–10 | 3.496 | 5.496 | 8.992 | −1.999 |
| EC–1 | 1.589 | 2.442 | 4.032 | −0.853 |
| EC–2 | 4.246 | 4.075 | 8.321 | 0.171 |
| EC–3 | 5.949 | 3.294 | 9.243 | 2.655 |
| EC–4 | 4.211 | 2.279 | 6.490 | 1.932 |
| LC–1 | 5.176 | 4.558 | 9.734 | 0.618 |
| LC–2 | 3.801 | 4.432 | 8.233 | −0.631 |
| LC–3 | 3.783 | 5.066 | 8.849 | −1.283 |
| LC–4 | 3.346 | 3.713 | 7.059 | −0.367 |
| LC–5 | 2.577 | 7.168 | 9.746 | −4.591 |

**Table 7.** The weights of the components of e-learning systems.

| | | Fuzzy ANP | | | Gray ANP | | |
|---|---|---|---|---|---|---|---|
| Cluster | The name of the component | Rank | The weight | Sum of the cluster | Rank | The weight | Sum of the cluster |
| Technology | Information Technologies Infrastructure | 1 | 0.167 | 0.577 | 1 | 0.185 | 0.625 |
| Technology | User Interface | 4 | 0.096 | | 4 | 0.102 | |
| Technology | System Security | 15 | 0.016 | | 15 | 0.013 | |
| Technology | Technical Support | 10 | 0.048 | | 12 | 0.023 | |
| Technology | Coordination and Communication | 12 | 0.022 | | 10 | 0.038 | |
| Technology | Offline Functionality | 16 | 0.011 | | 16 | 0.007 | |
| Technology | Diversity of the Instruments | 3 | 0.112 | | 3 | 0.109 | |
| Technology | Data Storage Space | 7 | 0.065 | | 5 | 0.087 | |
| Technology | Student Tracking System | 18 | 0.004 | | 18 | 0.002 | |
| Technology | Interactivity | 11 | 0.037 | | 8 | 0.059 | |
| Education | System Content Update | 19 | 0.003 | 0.252 | 19 | 0.001 | 0.209 |
| Education | Instructor Characteristics | 5 | 0.081 | | 7 | 0.059 | |
| Education | Education Program Content | 2 | 0.116 | | 2 | 0.109 | |
| Education | Course Content | 8 | 0.052 | | 9 | 0.039 | |
| E-learning | Special Programs for People with Disabilities | 6 | 0.073 | 0.171 | 6 | 0.084 | 0.166 |
| E-learning | The Use of Technology by Instructor | 9 | 0.049 | | 11 | 0.036 | |
| E-learning | The Use of Technology by Students | 14 | 0.020 | | 13 | 0.022 | |
| E-learning | Assessment and Fairness | 17 | 0.008 | | 17 | 0.002 | |
| E-learning | Motivation | 13 | 0.021 | | 14 | 0.017 | |

importance separately in the tables of their clusters which are around the pie chart in Figure 2. IT Infrastructure component is the most important component of Technology, Education Program Content component is the most important component of Education, and Special Programs for People with Disabilities component is the most important component of e–learning.

Pairwise comparisons of the components especially in ANP part of the proposed approach are done by 37 students from different e-learning programs in various countries in Europe. We made students do pairwise comparisons to analyze what is important for the students in e-learning systems. This was done especially because of the generation differences between instructors and students due to the technology usage of the system. For example, an instructor can have 100% knowledge of his/her field and transfer all of his/her knowledge to the students. But, if the technological capacity of the system is about 60% and the use of technology by the instructor is also 60%, then, total benefit for the students in this system is about 36%. Contrariwise, an instructor with 50% knowledge in a system with 100% technological capacity and 100% use of technology by him/her, then, total benefit for the students in this system is about 50% which is also about 50% more than the first example. Because of these kind of problems in e-learning systems, results of this study is important for both institutions and instructors, who are in e-learning system. Investors of the systems and institutions can invest in and improve e-learning systems according to the importance of components through the students' perspectives.

## Discussion

The main motivation of this study is to analyze the relations among the components of e-learning systems and prioritize them by using fuzzy DEMATEL and fuzzy ANP methods especially for the institutions and investors to make the systems perfect. While there is almost none of the studies in the literature analyzing the technological components together with the other components, this study is analyzing e-learning systems under three clusters; technology, education and e–learning. Evaluations of the components with pairwise comparisons were done by students from different e-learning programs in various countries in Europe as it is explained in the previous section. The aim of selecting students from different e-learning programs is to analyze the components through the perspective of students, who are the most important stakeholders of e-learning systems.

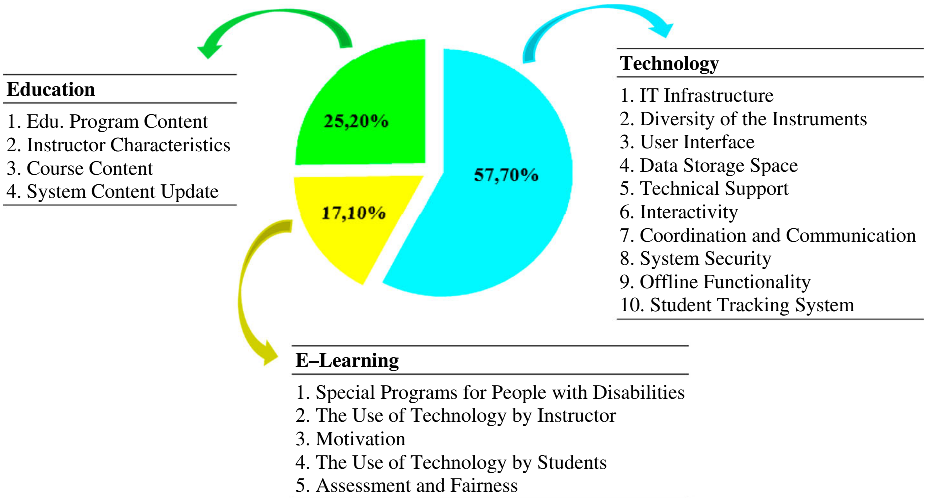


**Figure 2.** The Pie chart of the results as ranked components under clusters.

The main difference of this study from the previous studies is that almost all components without cost related components of e-learning was analyzed. Within our knowledge with the current literature, none of the studies analyzed all components and prioritize them, especially, educational components and technological components together. In order to observe this, a detailed comparison among the e-learning studies in the literature with this study is shown in Table 8. This is an important subject in today's world, because, all of the educational programs and most important people are accessible with the advanced internet and digital technology. Educational institutions cannot promote their e-learning programs only with their instructors or course contents anymore like decades ago when the technology is much worse than now. For example, most of the education materials of the most reputed universities can be accessible with today's online technology as videos, papers, online tests, online courses, etc. Classical promotion materials do not take attention of the new generation who are digital natives. Because, they have already known how to access something or use technology, at least more than digital immigrants.

Previous studies about e-learning can be grouped under two headings. One of them is the studies evaluating only the technological components of e–learning. Most of them analyzed the technological performance components without educational performance components. The other group of the studies are evaluating the educational performance, student satisfaction and other education related components without technological evaluation. With these kind of studies, observing the importance and comparison of the components objectively is really hard. Especially with the accessible technology and accessible reputed education contents with this technology, we should observe the importance of education and e-learning components together with technology components.

In the traditional education system, students can access only the educational institutions in their region. If they want to access the educational institutions in other regions, they accept transportation, accommodation and other education expenses. But, if they want to access an e-learning system, they need only a computer and an internet access. In today's world, students can access to any e-learning system from all around the world. This situation is also valid for e-learning institutions. They can hire anybody from all around the world without bringing them to the institution with a perfect IT infrastructure. Hence, e-learning systems cannot be assumed as a traditional education system and their components cannot be evaluated independently of each other. Investors of e-learning systems and institutions should invest in and improve e-learning systems according to the importance of all components of e-learning systems together.

**Table 8.** Detailed comparison of the e-learning studies.

| Reference | Technique | Evaluation or prioritization of the components | Evaluated components: Technological (T) | Educational (E) | E-learning (L) | Other (O) | The most important component(s) (if exists and related) or explanation of the study |
|---|---|---|---|---|---|---|---|
| Castillo-Merino and Serradell-López (2014) | The Structural Equation Model | ✓ | ✓ | ✗ | ✗ | ✗ | Motivation |
| Chuang and Lin (2014) | DEMATEL + ANP (Crisp) | ✗ | ✗ | ✗ | ✗ | ✓ | Analyzing customer citizenship behavior |
| Jain et al. (2015) | TOPSIS (Crisp) | ✗ | ✓ | ✗ | ✗ | ✗ | Evaluation of e-learning websites, not components |
| Islas-Pérez et al. (2015) | Non-hierarchical weight assessment (Crisp) | ✗ | ✓ | ✗ | ✓ | ✓ | Evaluation of e-learning tools, not components |
| Mohammed et al. (2016) | Fuzzy AHP | ✓ | ✗ | ✗ | ✗ | ✓ | Result and Action (Evaluated only 5 criteria) |
| Zadgari (2016) | Fuzzy ANP | ✗ | ✗ | ✗ | ✗ | ✓ | Assessment of E-Learning Service Quality |
| Okantey and Addo (2016) | Correlation and Linear Regression Analysis | ✓ | ✓ | ✗ | ✓ | ✓ | Perceived usefulness (O) |
| Islam (2016) | Statistical Techniques | ✗ | ✗ | ✗ | ✓ | ✓ | Moderating e-learning system use and outcomes |
| Aparicio et al. (2016) | The Structural Equation Model | ✗ | ✗ | ✗ | ✓ | ✓ | Cultural impacts on e-learning systems' success |
| Su et al. (2016) | Fuzzy DEMATEL+ Fuzzy ANP+ Fuzzy VIKOR | ✓ | ✓ | ✓ | ✗ | ✓ | Evaluating only cloud e-learning service strategies (12 criteria) including cost |
| Jain et al. (2016) | WDBA (Weighted Distance based App.) | ✗ | ✓ | ✗ | ✗ | ✗ | Evaluation of e-learning websites, not components |
| Garg and Jain (2017a) | Fuzzy AHP, COPRAS, VIKOR, WDBA | ✗ | ✓ | ✗ | ✗ | ✗ | Evaluation of e-learning websites, not components |
| Garg and Jain (2017b) | Fuzzy Set Theory | ✓ | ✓ | ✗ | ✓ | ✓ | Functionality (Prioritizing e-learning websites crit.) |
| Garg (2017a) | WDBA+ TOPSIS | ✗ | ✓ | ✗ | ✗ | ✗ | Evaluation of e-learning websites, not components |
| Garg (2017b) | Fuzzy AHP, COPRAS, WDBA | ✗ | ✓ | ✗ | ✗ | ✗ | Evaluation of e-learning websites, not components |
| Al-Samarraie et al. (2017) | Fuzzy DEMATEL | ✓ | ✓ | ✗ | ✗ | ✓ | Information quality (11 Criteria) |
| Yang, Su, and Wang (2017) | DEMATEL+ ANP+ VIKOR (Crisp) | ✓ | ✓ | ✗ | ✗ | ✗ | Convenience Type (E-Learning Service Quality) |
| Al–Rahmi et al. (2018) | The Structural Equation Model | ✓ | ✓ | ✗ | ✓ | ✗ | Self-efficacy (5 Criteria) |
| This Study | Fuzzy DEMATEL+ Fuzzy ANP | ✓ | ✓ | ✓ | ✓ | ✓ | Information Technologies Infrastructure (T), Education Program Content (E), Special Programs for People with Disabilities (L/O) (19 Criteria) |

In order to determine the relations between the components of e-learning systems, fuzzy DEMATEL method was applied in the first step of the study. Then, according to the relations obtained from fuzzy DEMATEL method, fuzzy ANP method was applied to 19 components in the second step to prioritize them. According to our findings shown in Table 7, Information Technologies Infrastructure as the most important component is 55.6 times more important than System Update, 2 times more important than Instructor Characteristics, 1.44 times more important than Education Program Content, which is also the second important component, and 3.2 times more important than Course Content as Education Cluster. Likewise, for E-learning Cluster, it is 2.28 times more important than Special Programs for People with Disabilities, 3.2 times more important than The Use of Technology by Instructor, 8.3 times more important than The Use of Technology by Students, 20.8 times more important than Assessment and Fairness and 7.9 times more important than Motivation. In its own cluster as Technology, it is 1.74 times more important than User Interface, 10.44 times more important than System Security, 3.48 times more important than Technical Support, 7.59 times more important than Coordination and Communication, 15.18 times more important than Offline Functionality, 1.49 times more important than Diversity of the Instruments, 2.57 times more important than Data Storage Space, 41.75 times more important than Student Tracking System and 4.5 times more important than Interactivity.

Education Program Content as the second most important component is 1.2 times more important than User Interface, 7.25 times more important than System Security, 2.4 times more important than Technical Support, 5.27 times more important than Coordination and Communication, 10.55 times more important than Offline Functionality, 1.78 times more important than Data Storage Space, 29 times more important than Student Tracking System, 3.14 times more important than Interactivity and almost equal to Diversity of the Instruments as Technology Cluster. For E-learning Cluster, it is 1.59 times more important than Special Programs for People with Disabilities, 2.37 times more important than The Use of Technology by Instructor, 5.8 times more important than The Use of Technology by Students, 14.5 times more important than Assessment and Fairness and 5.5 times more important than Motivation. In its own cluster as Education, it is 38.67 times more important than System Update, 1.43 times more important than Instructor Characteristics and 2.23 times more important than Course Content.

Additionally, as the comparisons among sub–clusters, main clusters also can be compared among each other. As it can be observed in Table 7 and Figure 2; the components of Technology Cluster are the most important components with 57.7%, the components of Education Cluster are the second with 25.2% and the components of E-learning Cluster are the third with 17.1% in e-learning systems.

Besides, as a more detailed study for investors, relations among the components shown in Appendix A can be evaluated. Besides being the most important component, Information Technologies Infrastructure affects 17 of the other components of e-learning systems. This means that the other components affected by Information Technologies Infrastructure are improved indirectly when Information Technologies Infrastructure are improved. So, cumulative benefit obtained from investing only Information Technologies Infrastructure is much more than expected. In Technology Cluster; User Interface affects 10 of the other components, System Security affects 2 of the other components, Technical Support affects 9 of the other components, Coordination and Communication affects 3 of the other components, Offline Functionality affects 5 of the other components, Diversity of the Instruments affects 11 of the other components, Data Storage Space affects 5 of the other components, Student Tracking System affects only 1 of the other components and Interactivity affects 8 of the other components. In Education Cluster; System Update affects 2 of the other components, Instructor Characteristics affects 9 of the other components, Education Program Content affects 14 of the other components and Course Content affects 11 of the other components. In E-learning Cluster, Special Programs for People with Disabilities affects 13 of the other components, The Use of Technology by Instructor affects 10 of the other components, The Use of Technology by Students affects 12 of the other components, Assessment and Fairness affects 6 of the other components and Motivation affects 6 of the other components.

This study is conducted for the prioritization of the components of e-learning systems and mainly discovered that most of the technological components are more important than the educational components and e-learning components. This means that an e-learning system with a digital immigrant instructor bad at using digital language can never be successful and survive. Besides, e-learning systems were took into account without any weight for any component. In other words, e-learning systems were not mentioned and described as extremely technological, with instructors like digital natives, etc. for the students not to affect their evaluations. With these situations, evaluations and analysis could be conducted without any tendency. According to the results of this study, a new study can also be conducted for the e-learning systems with extremely technological equipment and digital native instructors. But in that situation, conditions can also be like a traditional education system and results can be compared with it to interpret better.

## Conclusion

Information technologies have been affecting almost everything especially with the globalizing world. E-learning and distance learning have been becoming more popular in the last decades with the benefits of IT. Institutions and universities have been facing with different challenges with this increasing demand. Especially institutions with old technology equipment, adaption to these new systems can be really hard. The main purpose of this study was to analyze the components of e-learning systems objectively without cost factor. The results of the study were obtained through the perspective of students and it can be used to consider priorities while improving e-learning systems or investing to e–learning.

This study focused on three main components and 19 sub–components of e-learning systems. Fuzzy DEMATEL and fuzzy ANP were used to obtain the network structure and the weights of the components with analyzing them. Fuzzy DEMATEL enables to determine the causal relations among the components and fuzzy ANP enables to determine the importance of the components according to causal relations obtained from fuzzy DEMATEL. Application of crisp methodologies is a challenging situation in systems which include subjective judgements, both for evaluations and calculations. This study demonstrates the applicability of subjective judgements for e-learning systems by using fuzzy logic.

The main contribution of this study is to find out the relations among the components and prioritize them according to their relations, especially technology components with education components and e-learning components. According to the findings in this study, technology components are more important than education components and e-learning components. This means that IT infrastructure and its combination with other technology components are more important than instructor, instructor characteristics, course content, assessment, etc. So, according to the results, a perfect IT system, user interface, system security, diversity of the instruments and other technology components provides better advertising and brings better return than instructors, course contents and program contents.

Another important part of this study is that proposed methodologies can be also used for the other system including subjective judgements in both e-learning systems and other systems. Components can be expanded or contracted depending on the needs of institutions and students. The results of this study can also be used directly to evaluate e-learning suppliers. Integration of the proposed methodology with another MCDM methods can also be a further research area.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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## References

Al-Fraihat, D., Joy, M., & Sinclair, J. (2018). A comprehensive model for evaluating e-learning systems success. *Distance Learning*, *15*(3), 57–88.
Al-Qahtani, A. A., & Higgins, S. E. (2013). Effects of traditional, blended and e-learning on students' achievement in higher education. *Journal of Computer Assisted Learning*, *29*(3), 220–234.
Al-Samarraie, H., Teng, B. K., Alzahrani, A. I., & Alalwan, N. (2017). E-learning continuance satisfaction in higher education: A unified perspective from instructors and students. *Studies in Higher Education*, 1–17. doi:10.1080/03075079.2017.1298088.
Al–Rahmi, W., Alias, N., Othman, M. S., Alzahrani, A. I., Alfarraj, O., Saged, A. A., & Abdul Rahman, N. S. (2018). Use of e-learning by university students in Malaysian higher educational institutions: A case in Universiti Teknologi Malaysia. doi:10.1109/ACCESS.2018.2802325
Aparicio, M., Bacao, F., & Oliveira, T. (2016). Cultural impacts on e-learning systems' success. *The Internet and Higher Education*, *31*, 58–70.
Bai, C., & Sarkis, J. (2013). A grey-based DEMATEL model for evaluating business process management critical success factors. *International Journal of Production Economics*, *146*(1), 281–292.
Bajpai, S., Sachdeva, A., & Gupta, J. P. (2010). Security risk assessment: Applying the concepts of fuzzy logic. *Journal of Hazardous Materials*, *173*(1-3), 258–264.
Balaban, I., Bubas, G., & Pipan, M. (2011, September). Key elements of an e-learning course evaluation survey: An empirical validation. *2011–14th international conference on interactive collaborative learning (ICL)* (pp. 336–343).
Bhuasiri, W., Xaymoungkhoun, O., Zo, H., Rho, J. J., & Ciganek, A. P. (2012). Critical success factors for e-learning in developing countries: A comparative analysis between ICT experts and faculty. *Computers & Education*, *58*(2), 843–855.
Bongo, M. F., & Ocampo, L. A. (2017a). Exploring critical attributes during air traffic congestion with a fuzzy DEMATEL–ANP technique: A case study in Ninoy Aquino International Airport. *Journal of Modern Transportation*, 1–15. doi:10.1007/s40534-017-0150-x.
Bongo, M. F., & Ocampo, L. A. (2017b). A hybrid fuzzy MCDM approach for mitigating airport congestion: A case in Ninoy Aquino international airport. *Journal of Air Transport Management*, *63*, 1–16.
Brooks, S., & Davis, T. (2018, March). Engaging digital natives in an educational Setting. *Society for information technology & teacher education international conference, association for the advancement of computing in education (AACE)* (pp. 3761–3764).
Büyüközkan, G., Arsenyan, J., & Ertek, G. (2010). Evaluation of e-learning web sites using fuzzy axiomatic design based approach. *International Journal of Computational Intelligence Systems*, *3*(1), 28–42.
Büyüközkan, G., & Çifçi, G. (2012). A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. *Expert Systems with Applications*, *39*(3), 3000–3011.
Castillo-Merino, D., & Serradell-López, E. (2014). An analysis of the determinants of students' performance in e-learning. *Computers in Human Behavior*, *30*, 476–484.
Çelikbilek, Y., & Tüysüz, F. (2016). An integrated grey based multi-criteria decision making approach for the evaluation of renewable energy sources. *Energy*, *115*, 1246–1258.
Chuang, H. M., & Lin, C. K. (2014). Exploring learners' value co-creation behavior in e-learning environments. *The Development of Distance Learning in Taiwan Higher Education*, *1*, 195–215.
Colace, F., & De Santo, M. (2011). Evaluation models for e-learning platforms and the AHP approach: A case study. *The IPSI BGD Transactions on Internet Research*, *7*(1), 31–43.
Dargi, A., Anjomshoae, A., Galankashi, M. R., Memari, A., & Tap, M. B. M. (2014). Supplier selection: A fuzzy-ANP approach. *Procedia Computer Science*, *31*, 691–700.
Dimić, S., Pamučar, D., Ljubojević, S., & Đorović, B. (2016). Strategic transport management models—the case study of an oil industry. *Sustainability*, *8*(9), 954.
Dytczak, M., & Ginda, G. (2013). Is explicit processing of fuzzy direct influence evaluations in DEMATEL indispensable? *Expert Systems with Applications*, *40*(12), 5027–5032.

Fichten, C. S., Ferraro, V., Asuncion, J. V., Chwojka, C., Barile, M., Nguyen, M. N., … Wolforth, J. (2009). Disabilities and e-learning problems and solutions: An exploratory study. *Educational Technology & Society*, *12*(4), 241–256.

Gabus, A., & Fontela, E. (1972). *World problems, an invitation to further thought within the framework of DEMATEL*. Geneva, Switzerland: Battelle Geneva Research Center.

Garg, R. (2017a). E-learning website evaluation and selection using multi-attribute decision making matrix methodology. *Computer Applications in Engineering Education*. doi:10.1002/cae.21846.

Garg, R. (2017b). Optimal selection of e-learning websites using multiattribute decision-making approaches. *Journal of Multi-Criteria Decision Analysis*, *24*(3-4), 187–196.

Garg, R., & Jain, D. (2017a). Fuzzy multi-attribute decision making evaluation of e-learning websites using FAHP, COPRAS, VIKOR, WDBA. doi:10.5267/j.dsl.2017.2.003.

Garg, R., & Jain, D. (2017b). Prioritizing e-learning websites evaluation and selection criteria using fuzzy set theory. *Management Science Letters*, *7*(4), 177–184.

Gebel, M., Kupriyanova, V., Morais, R., & Colucci, E. (2014). E-learning in European higher education institutions. European University Association. Retrieved from http://www.eua.be/Libraries/publication/e-learning_survey

Gigović, L., Pamučar, D., Bajić, Z., & Milićević, M. (2016b). The combination of expert judgment and GIS-MAIRCA analysis for the selection of sites for ammunition depots. *Sustainability*, *8*(4), 372.

Gigović, L., Pamučar, D., Božanić, D., & Ljubojević, S. (2017). Application of the GIS-DANP-MABAC multi-criteria model for selecting the location of wind farms: A case study of Vojvodina, Serbia. *Renewable Energy*, *103*, 501–521.

Gigović, L., Pamučar, D., Lukić, D., & Marković, S. (2016a). GIS-Fuzzy DEMATEL MCDA model for the evaluation of the sites for ecotourism development: A case study of "Dunavski ključ" region, Serbia. *Land Use Policy*, *58*, 348–365.

Hadley, J., Kulier, R., Zamora, J., Coppus, S. F., Weinbrenner, S., Meyerrose, B., … Khan, K. S. (2010). Effectiveness of an e-learning course in evidence-based medicine for foundation (internship) training. *Journal of the Royal Society of Medicine*, *103*(7), 288–294.

Ho, C. L., & Dzeng, R. J. (2010). Construction safety training via e-learning: Learning effectiveness and user satisfaction. *Computers & Education*, *55*(2), 858–867.

Islam, A. N. (2016). E-learning system use and its outcomes: Moderating role of perceived compatibility. *Telematics and Informatics*, *33*(1), 48–55.

Islas-Pérez, E., Pérez, Y. H., Pérez-Ramírez, M., García-Hernández, C. F., & Pérez, B. Z. (2015). Multicriteria decision making for evaluation of e-learning tools. *Research in Computing Science*, *106*, 27–37.

Jain, D., Garg, R., & Bansal, A. (2015). A parameterized selection and evaluation of e-learning websites using TOPSIS method. *International Journal of Research & Development in Technology and Management Science*, *22*(3), 12–26.

Jain, D., Garg, R., Bansal, A., & Saini, K. K. (2016). Selection and ranking of e-learning websites using weighted distance-based approximation. *Journal of Computers in Education*, *3*(2), 193–207.

Jara Gutiérrez, N. P., & Prieto Soler, C. (2018). Impact of the differences between digital natives and immigrants on health science teaching: A systematic review. *Revista Cubana de Información en Ciencias de la Salud (ACIMED)*, *29*(1), 92–105.

Johnson, R. D., Hornik, S., & Salas, E. (2008). An empirical examination of factors contributing to the creation of successful e-learning environments. *International Journal of Human-Computer Studies*, *66*(5), 356–369.

Kang, H. Y., Lee, A. H., & Yang, C. Y. (2012). A fuzzy ANP model for supplier selection as applied to IC packaging. *Journal of Intelligent Manufacturing*, *23*(5), 1477–1488.

Kesharwani, A. (2019). Do (How) digital natives adopt a new technology differently than digital immigrants?-A longitudinal study. *Information & Management*. doi:10.1016/j.im.2019.103170.

Khan, N. Z., Ansari, T. S. A., Siddiquee, A. N., & Khan, Z. A. (2019). Selection of e-learning websites using a novel proximity indexed value (PIV) MCDM method. *Journal of Computers in Education*, *6*(2), 241–256.

Lee, M. C. (2010). Explaining and predicting users' continuance intention toward e-learning: An extension of the expectation–confirmation model. *Computers & Education*, *54*(2), 506–516.

Leidner, DE, & Jarvenpaa, SL. (1993). The information age confronts education: Case studies on electronic classrooms. *Information Systems Research*, *4*(1), 24–54.

Liaw, S. S., Huang, H. M., & Chen, G. D. (2007). Surveying instructor and learner attitudes toward e-learning. *Computers & Education*, *49*(4), 1066–1080.

Liu, S. H., Liao, H. L., & Peng, C. J. (2005). Applying the technology acceptance model and flow theory to online e-learning users' acceptance behavior. *Issues in Information Systems*, *4*(2), 175–181.

Liu, S. H., Liao, H. L., & Pratt, J. A. (2009). Impact of media richness and flow on e-learning technology acceptance. *Computers & Education*, *52*(3), 599–607.

Martínez-Torres, M. D. R., Toral, S. L., & Barrero, F. (2011). Identification of the design variables of eLearning tools. *Interacting with Computers*, *23*(3), 279–288.

Masud, M. A. H., & Huang, X. (2012). An e-learning system architecture based on cloud computing. *System*, *10*(11), 736–740.

Mehregan, M. R., Jamporazmey, M., Hosseinzadeh, M., & Mehrafrouz, M. (2011, September). Proposing an approach for evaluating e-learning by integrating critical success factor and fuzzy AHP. *International conference on innovation, management and service* (pp. 125–130). Singapore.

Mohammed, H. J., Kasim, M. M., AL-Dahneem, E. A., & Hamadi, A. K. (2016). An analytical survey on implementing best practices for introducing e-learning programs to students. *Journal of Education and Social Sciences*, *5*(2), 191–196.
Mohammed, H. J., Kasim, M. M., & Shaharanee, I. N. (2018). Evaluation of E-learning approaches using AHP-TOPSIS technique. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, *10*(1-10), 7–10.
Mohanty, R. P., Agarwal, R., Choudhury, A. K., & Tiwari, M. K. (2005). A fuzzy ANP-based approach to R&D project selection: A case study. *International Journal of Production Research*, *43*(24), 5199–5216.
Mosakhani, M., & Jamporazmey, M. (2010, September). Introduce critical success factors (CSFs) of e-learning for evaluating e-learning implementation success. *IEEE 2010 international conference on educational and information technology (ICEIT)* 1, V1-224-V1-228.
Mustafa, Y. E. A., & Sharif, S. M. (2011). An approach to adaptive e-learning hypermedia system based on learning styles (AEHS-LS): Implementation and evaluation. *International Journal of Library and Information Science*, *3*(1), 15–28.
Nilashi, M., & Janahmadi, N. (2012). Assessing and prioritizing affecting factors in e-learning websites using AHP method and fuzzy approach. *Information and Knowledge Management*, *2*(1), 46–61.
Okantey, M., & Addo, H. (2016). Effect of theoretical and institutional factors on the adoption of e-learning. *European Scientific Journal*, *12*(16), 462–473.
Ong, C. S., & Lai, J. Y. (2006). Gender differences in perceptions and relationships among dominants of e-learning acceptance. *Computers in Human Behavior*, *22*(5), 816–829.
Ozkan, S., & Koseler, R. (2009). Multi-dimensional students' evaluation of e-learning systems in the higher education context: An empirical investigation. *Computers & Education*, *53*(4), 1285–1296.
Papp, R. (2000). *Critical success factors for distance learning*. Americas Conference on Information Systems (AMCIS) 2000 Proceedings, 104, 1858-1861.
Pocatilu, P., Alecu, F., & Vetrici, M. (2010). Measuring the efficiency of cloud computing for e-learning systems. *WSEAS Transactions on Computers*, *9*(1), 42–51.
Prensky, M. (2001). Digital natives, digital immigrants part 1. *On the Horizon*, *9*(5), 1–6.
Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw Hill.
Saaty, T. L. (1996). *The analytic network process: Decision making with dependence and feedback; the organization and prioritization of complexity*. Pittsburgh: Rws publications.
Selim, H. M. (2007). Critical success factors for e-learning acceptance: Confirmatory factor models. *Computers & Education*, *49*(2), 396–413.
Sevkli, M., Oztekin, A., Uysal, O., Torlak, G., Turkyilmaz, A., & Delen, D. (2012). Development of a fuzzy ANP based SWOT analysis for the airline industry in Turkey. *Expert Systems with Applications*, *39*(1), 14–24.
Shee, D. Y., & Wang, Y. S. (2008). Multi-criteria evaluation of the web-based e-learning system: A methodology based on learner satisfaction and its applications. *Computers & Education*, *50*(3), 894–905.
Soong, M. B., Chan, H. C., Chua, B. C., & Loh, K. F. (2001). Critical success factors for on-line course resources. *Computers & Education*, *36*(2), 101–120.
Sridharan, B., Deng, H., Kirk, J., & Corbitt, B. (2010, January). Structural equation modeling for evaluating the user perceptions of e-learning effectiveness in higher education. *ECIS 2010: Proceedings of the 18th European conference on information systems* (pp. 1–13).
Su, C. H., Tzeng, G. H., & Hu, S. K. (2016). Cloud e-learning service strategies for improving e-learning innovation performance in a fuzzy environment by using a new hybrid fuzzy multiple attribute decision-making model. *Interactive Learning Environments*, *24*(8), 1812–1835.
Šumak, B., HeričKo, M., & PušNik, M. (2011). A meta-analysis of e-learning technology acceptance: The role of user types and e-learning technology types. *Computers in Human Behavior*, *27*(6), 2067–2077.
Sun, P. C., Tsai, R. J., Finger, G., Chen, Y. Y., & Yeh, D. (2008). What drives a successful e-learning? An empirical investigation of the critical factors influencing learner satisfaction. *Computers & Education*, *50*(4), 1183–1202.
Sung, Y. T., Chang, K. E., & Yu, W. C. (2011). Evaluating the reliability and impact of a quality assurance system for E-learning courseware. *Computers & Education*, *57*(2), 1615–1627.
Syamsuddin, I. (2012). Fuzzy multi criteria evaluation framework for e-learning software quality. *Academic Research International*, *2*(1), 139–147.
Tadić, S., Zečević, S., & Krstić, M. (2014). A novel hybrid MCDM model based on fuzzy DEMATEL, fuzzy ANP and fuzzy VIKOR for city logistics concept selection. *Expert Systems with Applications*, *41*(18), 8112–8128.
Tseng, M. L., Lin, R. J., & Chen, H. P. (2011). Evaluating the effectiveness of e-learning system in uncertainty. *Industrial Management & Data Systems*, *111*(6), 869–889.
Tzeng, G. H., Chiang, C. H., & Li, C. W. (2007). Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL. *Expert Systems with Applications*, *32*(4), 1028–1044.
Volery, T., & Lord, D. (2000). Critical success factors in online education. *International Journal of Educational Management*, *14*(5), 216–223.
Wang, C. S., & Lin, S. L. (2012, August). Combining fuzzy AHP and association rule to evaluate the activity processes of e-learning system. *Sixth international conference on genetic and evolutionary computing (ICGEC)* (pp. 566–570).
Wu, W. W., & Lee, Y. T. (2007). Developing global managers' competencies using the fuzzy DEMATEL method. *Expert Systems with Applications*, *32*(2), 499–507.

Yang, M., Su, C., & Wang, W. (2017). The use of a DANP with VIKOR approach for establishing the model of e-learning service quality. *EURASIA Journal of Mathematics Science and Technology Education*, *13*(8), 5927–5937.
Yuen, K. K. F. (2012, January). A multiple criteria decision making approach for E-learning platform selection: The primitive cognitive network process. *IEEE computing, communications and applications conference (ComComAp)* (pp. 294–298).
Zadgari, A. (2016). Assessment of e-learning service quality using the fuzzy analytic network process (Case study: E-learning Department of Shahid Beheshti University). *International conference on management & dynamic economics*.

## Appendices

### *Appendix A. The results of total relation matrix among the components of e-learning*

| Component | TC–1 | TC–2 | TC–3 | TC–4 | TC–5 | TC–6 | TC–7 | TC–8 | TC–9 | TC–10 | EC–1 | EC–2 | EC–3 | EC–4 | LC–1 | LC–2 | LC–3 | LC–4 | LC–5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TC–1 | 0.092 | **0.482** | **0.356** | **0.328** | **0.511** | **0.505** | **0.408** | **0.610** | **0.462** | **0.573** | **0.501** | **0.400** | **0.299** | 0.079 | **0.529** | **0.451** | **0.561** | **0.350** | **0.634** |
| TC–2 | 0.052 | 0.048 | 0.130 | 0.181 | **0.509** | 0.153 | **0.327** | 0.102 | **0.376** | **0.560** | 0.080 | **0.275** | **0.238** | 0.061 | **0.424** | **0.444** | **0.455** | 0.122 | **0.536** |
| TC–3 | 0.039 | 0.010 | 0.008 | 0.027 | 0.056 | 0.024 | 0.033 | **0.191** | **0.189** | 0.121 | 0.051 | 0.019 | 0.016 | 0.005 | 0.117 | 0.034 | 0.044 | 0.156 | 0.059 |
| TC–4 | 0.031 | 0.028 | 0.037 | 0.024 | **0.401** | **0.269** | 0.084 | **0.235** | 0.088 | **0.357** | **0.368** | 0.084 | 0.057 | 0.028 | **0.380** | **0.391** | **0.334** | 0.056 | **0.361** |
| TC–5 | 0.014 | 0.032 | 0.005 | 0.035 | 0.031 | 0.012 | 0.043 | 0.035 | 0.152 | **0.236** | 0.032 | 0.065 | 0.054 | 0.032 | **0.192** | 0.143 | 0.147 | 0.025 | **0.229** |
| TC–6 | 0.028 | 0.035 | 0.013 | 0.011 | 0.024 | 0.023 | 0.176 | **0.190** | 0.093 | 0.071 | 0.016 | **0.245** | 0.057 | 0.024 | **0.236** | 0.063 | **0.218** | 0.183 | **0.187** |
| TC–7 | **0.266** | **0.222** | 0.035 | 0.069 | 0.087 | 0.147 | 0.101 | **0.323** | 0.049 | 0.167 | 0.074 | **0.370** | **0.286** | **0.302** | **0.287** | **0.432** | **0.250** | **0.349** | **0.445** |
| TC–8 | **0.235** | 0.051 | 0.040 | 0.019 | 0.035 | **0.238** | **0.280** | 0.047 | 0.044 | 0.055 | 0.167 | 0.135 | 0.126 | 0.025 | **0.191** | 0.077 | 0.173 | 0.134 | **0.190** |
| TC–9 | 0.105 | 0.009 | 0.023 | 0.005 | 0.034 | 0.005 | 0.007 | 0.007 | 0.008 | **0.189** | 0.008 | 0.124 | 0.010 | 0.005 | 0.014 | 0.018 | 0.036 | 0.032 | 0.146 |
| TC–10 | 0.084 | **0.261** | 0.070 | 0.152 | **0.281** | 0.037 | 0.062 | 0.064 | 0.184 | 0.122 | **0.207** | **0.341** | 0.180 | 0.063 | **0.278** | **0.242** | **0.248** | 0.090 | **0.530** |
| EC–1 | 0.035 | 0.031 | 0.029 | 0.033 | 0.051 | 0.058 | 0.080 | 0.045 | 0.123 | 0.176 | 0.015 | 0.123 | 0.151 | 0.020 | 0.054 | **0.212** | **0.212** | 0.028 | 0.114 |
| EC–2 | 0.052 | 0.046 | 0.028 | 0.062 | 0.114 | 0.126 | **0.338** | 0.094 | 0.041 | **0.522** | 0.043 | 0.108 | **0.241** | **0.322** | **0.298** | **0.499** | **0.371** | **0.359** | **0.582** |
| EC–3 | **0.370** | **0.269** | 0.079 | 0.169 | **0.228** | **0.283** | **0.464** | **0.523** | 0.106 | **0.287** | 0.180 | **0.277** | 0.120 | **0.466** | **0.469** | **0.281** | **0.381** | **0.408** | **0.588** |
| EC–4 | 0.183 | 0.050 | 0.026 | 0.064 | 0.105 | **0.294** | **0.409** | **0.395** | 0.040 | **0.355** | 0.045 | **0.237** | **0.296** | 0.057 | **0.277** | **0.285** | **0.239** | **0.289** | **0.566** |
| LC–1 | **0.381** | **0.306** | 0.051 | **0.301** | **0.326** | **0.287** | **0.287** | **0.304** | 0.082 | **0.420** | 0.162 | **0.309** | **0.296** | 0.058 | 0.127 | 0.183 | **0.479** | **0.356** | **0.461** |
| LC–2 | 0.045 | 0.038 | 0.015 | 0.057 | **0.322** | 0.045 | **0.315** | **0.203** | 0.032 | **0.432** | 0.115 | **0.414** | **0.225** | **0.262** | **0.286** | 0.095 | **0.280** | 0.145 | **0.475** |
| LC–3 | 0.042 | 0.029 | **0.227** | 0.039 | 0.168 | **0.238** | **0.205** | **0.260** | **0.245** | **0.332** | **0.235** | **0.226** | **0.249** | 0.181 | 0.074 | **0.221** | 0.082 | **0.280** | **0.449** |
| LC–4 | **0.280** | 0.177 | **0.347** | 0.059 | 0.101 | 0.047 | 0.057 | 0.067 | **0**.289 | 0.131 | 0.117 | 0.064 | **0.263** | 0.172 | **0.269** | 0.067 | **0.263** | 0.069 | **0.507** |
| LC–5 | 0.020 | 0.022 | 0.020 | 0.038 | **0.356** | 0.020 | 0.062 | 0.031 | 0.054 | **0.388** | 0.026 | **0.260** | 0.131 | 0.117 | 0.056 | **0.292** | **0.293** | **0.281** | 0.109 |

## *Appendix B. Normalized supermatrix*

| Component | TC–1 | TC–2 | TC–3 | TC–4 | TC–5 | TC–6 | TC–7 | TC–8 | TC–9 | TC–10 | EC–1 | EC–2 | EC–3 | EC–4 | LC–1 | LC–2 | LC–3 | LC–4 | LC–5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TC–1 | 0.000 | 0.487 | 0.904 | 0.664 | 0.207 | 0.310 | 0.106 | 0.312 | 0.582 | 0.135 | 0.608 | 0.069 | 0.073 | 0.000 | 0.039 | 0.092 | 0.085 | 0.121 | 0.026 |
| TC–2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.250 | 0.000 | 0.194 | 0.000 | 0.174 | 0.192 | 0.000 | 0.189 | 0.080 | 0.000 | 0.230 | 0.240 | 0.241 | 0.000 | 0.127 |
| TC–3 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.230 | 0.132 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| TC–4 | 0.000 | 0.000 | 0.000 | 0.000 | 0.212 | 0.208 | 0.000 | 0.163 | 0.000 | 0.118 | 0.302 | 0.000 | 0.000 | 0.000 | 0.184 | 0.144 | 0.164 | 0.000 | 0.077 |
| TC–5 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.155 | 0.000 | 0.000 | 0.000 | 0.000 | 0.186 | 0.000 | 0.000 | 0.000 | 0.107 |
| TC–6 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.097 | 0.000 | 0.000 | 0.000 | 0.026 | 0.000 | 0.000 | 0.018 | 0.000 | 0.023 | 0.000 | 0.016 |
| TC–7 | 0.195 | 0.159 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.051 | 0.000 | 0.000 | 0.000 | 0.088 | 0.210 | 0.367 | 0.046 | 0.079 | 0.063 | 0.075 | 0.078 |
| TC–8 | 0.328 | 0.000 | 0.000 | 0.000 | 0.000 | 0.214 | 0.066 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.011 | 0.000 | 0.000 | 0.000 | 0.010 |
| TC–9 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.104 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| TC–10 | 0.000 | 0.132 | 0.000 | 0.000 | 0.139 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.063 | 0.132 | 0.000 | 0.000 | 0.034 | 0.105 | 0.085 | 0.000 | 0.082 |
| EC–1 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.050 | 0.040 | 0.000 | 0.000 |
| EC–2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.236 | 0.000 | 0.000 | 0.068 | 0.000 | 0.000 | 0.218 | 0.166 | 0.068 | 0.151 | 0.096 | 0.195 | 0.104 |
| EC–3 | 0.214 | 0.103 | 0.000 | 0.000 | 0.036 | 0.115 | 0.174 | 0.042 | 0.000 | 0.048 | 0.000 | 0.121 | 0.000 | 0.409 | 0.074 | 0.045 | 0.055 | 0.261 | 0.117 |
| EC–4 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.083 | 0.059 | 0.030 | 0.000 | 0.048 | 0.000 | 0.110 | 0.167 | 0.000 | 0.066 | 0.048 | 0.055 | 0.209 | 0.108 |
| LC–1 | 0.161 | 0.120 | 0.000 | 0.336 | 0.073 | 0.031 | 0.048 | 0.024 | 0.000 | 0.016 | 0.000 | 0.025 | 0.042 | 0.000 | 0.000 | 0.000 | 0.027 | 0.062 | 0.043 |
| LC–2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.045 | 0.000 | 0.073 | 0.036 | 0.000 | 0.047 | 0.000 | 0.179 | 0.125 | 0.058 | 0.026 | 0.000 | 0.027 | 0.000 | 0.044 |
| LC–3 | 0.000 | 0.000 | 0.039 | 0.000 | 0.000 | 0.038 | 0.043 | 0.014 | 0.055 | 0.053 | 0.027 | 0.038 | 0.051 | 0.000 | 0.000 | 0.021 | 0.000 | 0.034 | 0.025 |
| LC–4 | 0.102 | 0.000 | 0.057 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.057 | 0.000 | 0.000 | 0.000 | 0.032 | 0.000 | 0.018 | 0.023 | 0.022 | 0.000 | 0.036 |
| LC–5 | 0.000 | 0.000 | 0.000 | 0.000 | 0.037 | 0.000 | 0.000 | 0.000 | 0.000 | 0.018 | 0.000 | 0.023 | 0.000 | 0.000 | 0.000 | 0.000 | 0.017 | 0.043 | 0.000 |