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REINVENTING UNIVERSITY.
THE DIGITAL CHALLENGE IN HIGHER EDUCATION

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4. EVALUATION OF UNIVERSITIES QOS USING FUZZY COGNITIVE MAPS[1]

by Panagiotis Perivolaris* and Vassilis Stylianakis**

Abstract: *HEIs' digital transformation is revealing a variety of new opportunities for improving not only their current online teaching practices but also their overall business operations. The processing of data can be further expanded using a range of advanced techniques, as is the case of cognitive tree maps, fuzzy networks, or even evolutionary algorithms, to examine and explain how the behaviour of a complex system, such as an HEI, is affected by the multiple conditions changing over time. The design of such a tool and the development of an optimization system that can determine ideal values for these aspects are covered in the proposal. The present work introduces a tool for the evaluation of the HEI Quality of Service factor (HEI-QoS), using a Fuzzy Cognitive Map designed for a specific purpose. The FCM model uses eight concepts which characterize the HEI operation and performance, taking into consideration the most well-known HEI rankling tools. Concepts values can be estimated from a field research analysis inside the HEI resulting in a very useful internal evaluation tool for a HEI.*

Keywords: Optimization, Fuzzy Logic, Fuzzy Cognitive Maps, Decision Making

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Abstract: *La trasformazione digitale degli IIS sta rivelando una serie di nuove opportunità per migliorare non solo le loro attuali pratiche di insegnamento online, ma anche le loro operazioni aziendali globali. L'elaborazione dei dati può essere ulteriormente ampliata utilizzando una serie di tecniche avanzate, come nel caso delle mappe cognitive ad albero, delle reti fuzzy o anche degli algoritmi evolutivi, per esaminare e spiegare come il comportamento di un sistema complesso, come un IIS, sia influenzato dalle molteplici condizioni che cambiano nel tempo. Il design di tale strumento e lo sviluppo di un sistema di ottimizzazione in grado di determinare i valori ideali per questi aspetti sono oggetto della presente proposta. Il seguente lavoro introduce uno strumento per la valutazione del fattore HEI Quality of Service (HEI-QoS), utilizzando una Fuzzy Cognitive Map progettata per lo scopo specifico. Il modello FCM utilizza otto concetti che caratterizzano il funzionamento e le prestazioni dell'HEI, prendendo in considerazione i più noti strumenti di rankling dell'HEI. I valori dei concetti possono essere stimati da un'analisi di ricerca sul campo all'interno dell'IIS, risultando in uno strumento di valutazione interna molto utile per un IIS.*

Parole chiave: Ottimizzazione, Logica Fuzzy, Mappe Cognitive Fuzzy, Processo Decisionale

Introduction

According to the European Union Digital Education Action Plan (2021-2027) (European Commission), digitalization of the Higher Education Institutions (HEI) emerges as a major priority. Implementation of new technologies will lead to modern and more efficient teaching and learning methods. Also, will have a great effect on institutions' overall operations such as administrative and management.

Students' learning is the most important HEI operation and, therefore, should be highly monitored. The quality of the courses provided constitutes the greater factor of institution quality along with the overall knowledge and skills provided to graduates to be used in their future careers. Furthermore, HEIs should provide an environment and overall services to teachers, administrative staff and students. University facilities include student's dormitory, sports hall, library, etc. Laboratories, equipment, and amphitheatres are also very important regarding learning services. Administrative effectiveness and teachers' support to students should also be considered in the HEI evaluation of services.

Improving the Quality of Service (QoS) in universities has constantly been an important topic of research and discussion, driven by the need to enhance the educational experience for students, streamline administrative processes, and ensure efficient resource allocation. Some areas of current work and research activities related to QoS in universities include: Online and distance education, boosted by the COVID-19 epidemic and focused on improving the overall quality of service for online learning environments, providing reliable internet connections, and optimizing QoS for virtual classrooms; student Satisfaction and Engagement, as key indicators of QoS, exploring strategies to measure and improve these aspects, such as analyzing student feedback, implementing innovative teaching methods, and enhancing student support services; Administrative Efficiency, essential for improving QoS in universities, investigating the use of technology, automation, and data analytics to simplify tasks related to admissions, registration, financial aid, and other administrative functions; resource allocation, whereby efficient resource allocation is crucial for maintaining high QoS and researchers are developing models and algorithms to optimize the allocation of financial, human, and infrastructure resources to support teaching, research, and administrative activities; Quality

Assurance and Accreditation, ensuring the quality of academic programs and adherence to accreditation standards, with research involving the development of assessment frameworks, tools, and methodologies to evaluate and maintain the quality of educational offerings; Technological Infrastructure, the upgrading and maintaining of which is essential for QoS, with areas to investigate including the implementation of high-speed internet, advanced learning management systems, and cybersecurity measures to support teaching and research activities; pedagogical innovation, because innovative teaching methods and curriculum design can significantly impact QoS. In the latter case, researchers may focus on pedagogical innovations, including blended learning, flipped classrooms, and active learning strategies (ECOLHE Project, 2023), (Jacek Pietrucha, 2018), (Adina-Petruta Pavel, 2015), (Moed, H.F., 2017).

Nowadays, as artificial intelligence is beginning to become implemented in ever-increasing areas of our everyday actions, Fuzzy Cognitive Maps (FCMs) have emerged as mathematical models used to represent and analyze complex systems. They blend fuzzy logic with cognitive mapping, enabling the depiction of intricate relationships between variables (Glykas, 2010), (Aguilar, 2005). The work uses Fuzzy Cognitive Maps (FCM) in overall HEI Quality of Service (QoS). For that purpose, an FCM model was built using FCM Expert Software (Nápoles *et al.*, 2018) depicting factors influencing HEI operation. FCM depicts the correlation and influence between them, resulting in a general QoS that institutes provide. FCMs are very helpful in modelling systems characterized by ambiguity among their variables. Regarding university services, there is a difference in how everyone perceives the services provided. The views and the resulting opinions, or, effectively, the perceived Quality of Service by the various stakeholders, can depend on factors such as the role played by each stakeholder, i.e., whether the stakeholder is a student, a tutor or a member of the administrative personnel; the level of funding an institution receives; the location of the institution, which can influence everyday life of the stakeholders; the quality of the teaching material, including labs, classrooms and libraries, physical or electronic ones. All these factors also interact with one another, making the model outlining their interactions complex. This challenge seems very suitable for the application of the concept of Fuzzy Cognitive Maps.

The advantages of applying Fuzzy Cognitive Maps in complex and evolving systems can be further and continuously expanded, leveraging the evolution of computer and software capabilities. FCMs can be used in multi-criteria decision-making scenarios inherent in QoS management. Fuzzy Cognitive Maps, in this area, are instrumental in developing methods to incorporate user preferences and priorities into the decision-making process. The development of FCM-based strategies to improve QoS, includes resource allocation algorithms, load balancing techniques, and fault tolerance mechanisms based on FCM predictions.

Future advances in Artificial Intelligence can be applied to promote the elaboration of the weights of the concepts, improving, or overtaking, the role of experts' opinions, by means of methods and algorithms in the field of Genetic Algorithms, Neuron Networks or Deep Learning, among others (Papageorgiou, 2014), (Jetter e Kok, 2014), (Stach *et al.*, 2005, 2007, 2010).

The Present work introduces an HEI-QoS factor that measures overall university performance and can be used as an internal evaluation tool regarding HEI operations. A Fuzzy Cognitive Map (FCM) model is designed and tested through different scenarios for that purpose. FCM is composed of eight concepts depicting different fields which affect HEI operation, such as funding, professors' effectiveness, state of institution facilities both educational and cultural, laboratory equipment, administrative staff effectiveness, HEI location and HEI funding.

The combination of all these concepts and their relations forms the FCM model, leading to the output of a HEI-QoS scaled in three levels of operation, i.e., Low, Medium and High. The above concepts' values can be measured through internal HEI field research throughout all personnel involved in everyday operations, academic and administrative staff, students, and external stakeholders. Since each part perceives each concept differently, Fuzzy logic is a perfect fit to depict values regarding each concept.

The rest of this work is organized as follows: Section II presents the related work on this topic, showing promising applications in various fields of interest. After this, section III briefly reviews FCM theory and presents the arguments for using a tool to apply in the field of Higher Education. The formulation of the Model is depicted in section IV, along with the detailed factors and their interactions, where each concept is explained analytically. This is followed by simulation results and analysis in section V, where the results are presented and analyzed along with the system's sensitivity to any changes in the original hypotheses. Finally, the conclusions are given along with suggestions about the future possibilities of hybrid models based on this original idea and the prospects of applying them in even more complex cases.

1. Related Work

Though Fuzzy Logic and Fuzzy Cognitive Maps are used extensively in applied sciences and engineering (Papageorgiou, 2014), their use in estimating an overall HEI QoS has not been so well studied so far.

Factors that influence undergraduate students' participation in Malaysia are explored (Mustapha *et al.*, 2010) through a case study. The research includes 25 undergraduate students following communication courses. Analysis reveals four factors of influence. The first one is positive lecture traits, followed by positive classroom traits. Engaging class content and conducive physical settings ranked third and four,th respectively. On the other hand, negative classmate traits, lecturer traits, and student traits, followed by non-conducive physical settings and uninteresting and difficult class content, are factors that discourage students from participating. These factors characterize an overall student's behavior, which constitutes a parameter in the FCM model of this work.

An FCM of Learning Management Systems (LMS) users' quality of interaction in HE blended-learning environments is presented in Sofia Balula Dias *et al.* (2014). Researchers introduce an FCM-QoI (Quality of Interaction) model, which can provide concepts of interconnection and casual dependencies representation, revealing perspectives at the micro and macro analysis level. Professors' and students' QoI are estimated when both interact with LMS in blended-learning environments. Model implementation results can assist teaching staff and decision-makers of HEIs in understanding stakeholders' needs within the teaching and learning practices.

A sustainable supply chain management Framework in an HE laboratory is introduced (Purnomo et.al, 2020). An extensive literature overview regarding FCM and their applications for use in future studies is presented (Jetter e Kok, 2014). The authors, besides a theoretical framework presentation of FCM modelling, offer numerous uses in engineering, risk assessment, medicine and environmental sciences, the prediction of outcomes such as revenue and cost, environmental sciences and many other fields.

According to (Purnomo *et al.*, 2020), “when they were originally invented, FCM were intended to make complex political, economic, or social problems”. Taking that aspect, the present work applies FCM in HEIs QoS, another field of research. Note that an HEI is a community itself, so interactions between stakeholders from inside and outside affect the institution’s operation during periods.

2. Fuzzy cognitive maps

A model based on FCM is designed by building a model of the system involving boxes and connections. The boxes are usually called ‘factors’ or ‘concepts’ and represent anything that can be expressed as a variable but does not have to be quantifiable or related to data, meaning it can capture knowledge without involving necessarily empirical data. Arrows represent the connections and are usually referred to as edges. Edges are used to represent causal links between factors showing direct casual interaction. This way, the propagation of interactions or influences through a system is explored by the Fuzzy cognitive-based system (Barbrook-Johnson, Penn, 2002).

The construction of FCM maps is accomplished in three basic stages (Papageorgiou, 2014).

1) The list of factors: In the first stage, a list of factors that may be described as variables and so be included in the map is compiled. This serves as the system’s definition. The factors can be abstracted, but they normally need to possess some level of comparability in their abstraction or be simplified, for that matter, to some extent that allows for comparison. They are frequently based on experts’ opinions and are usually few to preserve the simplicity of the following stage.

2) The design of the map and its precise connections. The connections between the elements are defined at this stage, together with details such as the value of the edge weight, the direction the arrows should take, and whether they should be positive or negative (i.e., growing or decreasing). It should be noted that a positive connection means that factors move together, whereas a negative connection means that they move inversely. Factors do not exhibit positive or negative effects, contrary to what can be mistakenly believed based on day-to-day experience.
3) Analyses performed and their interpretation. The elaborated analysis is carried out using the static map, whose factor values and edge values have been established. The experts and stakeholders evaluate the findings once more so that they can assess them considering their mental models of causal structure and challenge, affirm, or modify their assumptions about the structure under investigation. This kind of FCM analysis results in an extrapolation or summary of the causal reasoning present in the map. The results of this reflection can be used to initiate changes and improvements to the original values.

The title refers to Bart Kosko who through his work (Kosko, 1986) 1986 introduced FCM as *"…fuzzy-graph structures for representing causal reasoning"*. Kosko extends cognitive maps (Axelrod, 1976), creating a way of modelling systems which are affected by a series of factors (concepts) during the time. Concept interaction from one concept to another is depicted through direct links, which can be positive or negative. Links present the relation between the concepts, and each one has a value that depicts the strength of the relation among them.

Bart Kosko (1993) depicts the structural similarity of FCMs to neural networks. Neurons can take values of either 1 (on) or 0 (off). Unlike them, concepts can take values between [0,1] or [-1,1] depicting the fuzziness of the system. The activation of a concept affects other concepts that are affected by it positively or negatively. The triggering propagates throughout the network until it reaches a steady state. The adjacency matrix mathematically represents the effect between concepts. Furthermore, a concept can be a decision node or an output for measuring the level of a value. A simple FCM system is depicted with FCM Expert Software (Nápoles *et al.*, 2018) in Figure 1 followed by the adjustment matrix of Table 1.

Figure 1: A simple FCM model

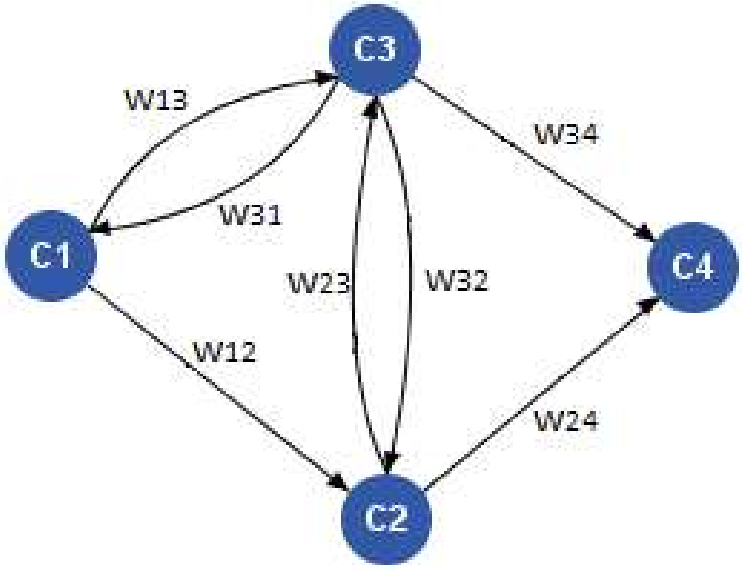


Table 1: Adjustment Matrix of Fig.1 FCM model

	$C1$	$C2$	$C3$	$C4$
$C1$	0	w_{12}	w_{13}	0
$C2$	0	0	w_{23}	w_{24}
$C3$	w_{31}	w_{32}	0	w_{34}
$C4$	0	0	0	0

In the example of Figure 1 node C4 all links flow in and therefore is called receiver casualty. If all links are flowing out of a node the concept is called the driver concept. All the other nodes are called ordinary concepts. (C1, C2, and C3 are ordinary concepts in Figure 1). A complex map can include a very large number of concepts, and in that case, the adjustment matrix takes its general form in Table 2 below.

Table 2- Adjustment Matrix General Form

$$\begin{array}{cccc} & C1 & & Ci \\ C1 & 0 & \cdots & w_{1i} \\ & \vdots & \ddots & \vdots \\ Ci & w_{i1} & \cdots & 0 \end{array}$$

Each concept of the model can be activated through a triggering function. The most common functions used for triggering are Bivalent, Trivalent, Hyperbolic, Saturation and Sigmoid. The mathematical representation of an FCM is given in Equation 1.

$$A_i(k+1) = f\left(A_i(k) + \sum_{j=1}^{N} A_j(k) \cdot w_{ij} \right) \qquad (1)$$

Where: $A_i(k),\ A_i(k+1)$ are the values of concept A_i in time k and k+1 respectively and A_j is the cause node. Note that the value in time k+1 is calculated by the sum of the previous value of A_i with the sum product of the value A_j of the cause nodes and links weights.

A useful example for understanding FCM usage in engineering is given in Papageorgiou Elpiniki *et al.* (2003). A chemical process problem is given, and a process control system adjusts parameters with the use of FCM leading to the desired system state.

Fuzzy Cognitive Maps are used in other fields of research as well. Re-approaching fuzzy cognitive maps to increase the knowledge of a system is explored in (Mpelogianni e Groumpos, 2018) providing very useful results regarding complex systems. Zero energy buildings modelling using new equations and FCM developed in (Vergini e Groumpos, 2018). Another topic of FCM usage is in health science regarding disease detection (Apostolopoulos et.al, 2021) and Parkinson (Groumpos e Anninou, 2012).

3. Model Formulation

Present work introduces Fuzzy Cognitive Mapping in the estimation of a HEI-Quality of Services (HEI-QoS) indicator. HEI quality is a very important factor as it depicts its overall recognition and reputation of HEI throughout the Higher Education community worldwide.

The nature of software solutions, with their accounting and logistical precision, flexibility, and ongoing technical advancement, provides choices for the monitoring of different success indices in both quantitative and qualitative measures. Measures used might be both objective and subjective indexes. The amount of participation, the subsequent dropout rate, the level of student involvement, and the various degrees of text success are some objective metrics. Subjective measures could include teachers', students', or administrative staff's satisfaction.

These could be assessed at many levels of abstraction, starting at the university level and descending in depth to specific schools, departments, classes, lessons, and even individual tests or sections of the course material. Because digital operations are automated, it is possible to utilise online questionnaires to continuously track the patterns of these satisfaction indexes, providing useful information to all stakeholders. These metrics may include the volume of transactions and the duration of operations in the administrative field and day-to-day operations. These metrics can be cross-correlated with other variables and used to draw illuminating conclusions when presented as curves and time series.

Several concepts are taken into consideration forming the overall quality of a university. These concepts and the relations among them are extracted from experts. The present work uses the 8 most valuable parameters and forms an FCM to produce an overall QoS measurement regarding HEI performance. These concepts were based on the QS World University Rankings (QSWUR), Times Higher Education World University Rankings (THEWUR), and the Academic Ranking of World Universities (ARWU), generally considered dependable University evaluation methods.

According to Jacek Pietrucha (2018) and Adina-Petruta Pavel (2015), ARWU is based on the quality of education, the quality of faculty, the research output and academic performance. These criteria can be composed according to the following concepts of an FCM model:

1. Quality of Education: Learning Facilities, Professors Effectiveness, Laboratories Equipment.
2. Quality of Faculty: Learning Facilities, Laboratories Equipment, and Cultural Facilities.
3. Research Output: Learning Facilities, Professors Effectiveness, Laboratories Equipment, and Students Performance.
4. Academic Performance: Professors’ Effectiveness, Students’ Performance and Administrative Services.

The second-ranking method, THEWUR, uses a different approach (Moed, 2017) and takes into consideration 13 performance indicators which cover 5 key areas:

1. Teaching: Learning Facilities, Professors Effectiveness, Laboratories Equipment.
2. Citations: Professors Effectiveness.
3. Research: Learning Facilities, Professors Effectiveness, Laboratories Equipment, and Students Performance.
4. International outlook: Learning Facilities, Professors Effectiveness, Laboratories Equipment and HEI Location.
5. Industry income - innovation: Funding, Professors Effectiveness, Laboratories Equipment, and Students Performance.

The third, QSWUR, uses six indicators (Estrada and Cantu,2022) and this work uses the four being of the biggest importance:

1. Academic Reputation: Learning Facilities, Professors Effectiveness, Laboratories Equipment, Cultural Facilities, HEI Location.
2. Employer reputation: Professors Effectiveness and Administrative Services.
3. Faculty/student Ratio: Professors Effectiveness and Administrative Services.
4. Citations per faculty: Professors Effectiveness.

Based on the consideration of these criteria, the concepts used in the design of FCM model cover the above indicators of the most used ranking methods. The concepts which form the FCM are:

3.1 C1: Funding

Funding is the most critical resource for the operation in every organization and HEIs could not be an exception to that rule. Adequate funding is essential for facility upgrades and proper maintenance, staff payrolls, university operational costs, research resources and staff involvement, laboratory equipment and many others. Funding could come from Government decisions and legislation, internal resources utilization, students' enrollments, donations etc. Current work combines all these parameters into one general concept called Funding. Note that in the proposed model, research constitutes a driver concept of the map. It affects all the other concepts of the map except students' attitude (C7) and location (C8). That is a very logical hypothesis because the bigger the revenue, the better the facilities, and the laboratories, professors and staff performance will be.

Thus, funding being the most influential factor is attributed to the greatest values regarding the weights of concepts' connection. It doesn't contribute to the overall HEI-QoS but affects the above factors which are vital in university operations. Experts' opinions conclude that funds mostly interacted with factors C2 and C3 (learning and cultural facilities) with values of 0.77 and 0.62 respectively and also with C5 (professors' effectiveness) with a weight value of 0.56. Administrative staff also is correlated with a weight value of 0.31.

3.2 C2: Learning Facilities

Adequate infrastructure, including modern classrooms, laboratories, libraries, and IT resources, contributes to a positive learning environment.

The learning facilities concept depicts the number and condition of buildings, amphitheatres, laboratories, and libraries that an HEI can provide to its academic staff. Having a large number of learning facilities will increase professors and administrative effectiveness and also will characterise the University

QoS provided. On the other hand, if their state is poor, the factor will be negative, regarding the correlated casualties.

Learning facilities are a very important factor including laboratories and are correlated with professors' effectiveness and students' performance with weights of 0.43 and 0.59 respectively. According to the experts' opinions, learning facilities should be involved in evaluating the overall HEI-QoS being attributed a 0.48 value.

3.3 C3: Cultural Facilities

An HEI should be capable of providing cultural facilities as well. These include dorm and sports facilities, museums, cultural and conference centres, worship places etc. Cultural facilities affect academic staff and students' attitudes, as well as the overall HEI-QoS. In fact, the latter can be affected not only by funding but from administration staff, too. Administrative services will lead to a high-quality usage of cultural facilities that an HEI can provide.

Cultural facilities according to experts are affecting students' performance with a weight of 0.51 and are involved in the evaluation of the overall HEI-QoS being attributed a 0.37 value.

3.4 C4: Administrative Services

Quality of administration is very important in an HEI operation. Learning facilities state will affect services provided because the better the facilities are the better will be the environment and the tools that staff will use in order to fulfil its purpose. The administration will affect professors' work, but professors affect the administration too. For example, the more research projects a teacher manages the more administrative services will need. The administration also characterises the HEI-QoS itself.

The administrative staff is correlated with professors' effectiveness with a weight of 0.30 and is involved in the evaluation of the overall HEI-QoS being attributed a 0.31 value.

3.5 C5: Professors Effectiveness

Professors are the backbone of an HEI. Universities' main goal is the production and diffusion of knowledge. Professors are the means for achieving these goals. That concept includes research work, teaching skills and professors' recognition. Poor rating of effectiveness means poor learning outcomes for students, low research quality and overall low-quality HEI and for that reason has the greater weight in HEI-QoS. That concept is correlated with administrative staff and students' attitudes in both directions, with facilities provided and the state of laboratories.

According to experts' opinions professors' effectiveness is correlated with administrative staff services, laboratory equipment and students' performance with 0.10, 0.35, and 0.45 weights respectively, but not with the remaining factors. The professors' concept is involved in evaluating the overall HEI-QoS being attributed a 0.65 value.

3.6 C6: Laboratories Equipment

Laboratories are equivalent to factories regarding the production of knowledge. For that reason, should be very well equipped and have research staff of high quality. Funding and learning facilities are correlated with that concept together with professors' effectiveness and students' attitudes in both directions. A good professor needs a good laboratory which affects the students' attitude, while, at the same time, a good laboratory needs a good professor who can benefit to the maximum from its equipment and facilities resulting in a positive effect on students' attitude.

Laboratories equipment is directly correlated with professors' effectiveness and students' performance with weights 0.63 and 0.44 respectively, while it does not affect the values of the other concepts, according to the expert's opinion. It doesn't contribute to the overall HEI-QoS but affects the above factors which are vital in university operations.

3.7 C7: Students' performance

Students' attitude regarding their overall performance is a concept that includes success in exams, participation in classes, the dropout rate of courses, or the students' wellbeing, their behaviour towards their colleagues and their teachers. Good professors affect their students positively and vice versa. Facilities condition is also correlated with attitude of students. The location of the university may play a minor role too.

Students' performance is highly correlated with administrative staff and of course with professors' concept with weights 0.12 and 0.53 respectively. Students' performance is involved in evaluating the overall HEI-QoS being attributed a 0.08 value.

3.8 C8: HEI Location

The geographical location of a university affects the quality of life for students and their access to internships, networking opportunities, and cultural experiences.

The location of the university may affect in a minor way students' attitudes and the overall HEI-QoS. That's because in most cases HEIs which are far away from big cities and access to them is difficult (poor transportation for example) attract fewer students and academic staff.

University location according to experts is not a very important concept but is highly correlated with students' performance with a weight of 0.17. That is explained because the more attractive the place is, the more students feel comfortable living there and studying.

According to the experts' opinion, it is not heavily correlated with the other factors involved in our model. The location concept is involved in the evaluation of the overall HEI-QoS being attributed a 0.08 value.

3.9 HEI-QoS (output)

The final concept forms the output node of the model. It affected teaching and administrative staff, facilities and laboratory conditions and in a minor way from the location of the HEI. HEI-QoS is affected by the concepts C2, C3, C4, C5, C7 and C8. Both C1 (funding) and C6 (laboratory equipment) are not directly correlated with HEI-QoS output but affect other concepts indirectly. The FCM model for HEI-QoS estimation is depicted in Fig 2. The model was constructed and analyzed with FCM expert software (Nápoles G et.al, 2018). The adjustment matrix of the model is given in Table 3. The weights of each concept correlation were calculated by experts.

Figure 2: FCM model for a HEI-QoS estimation

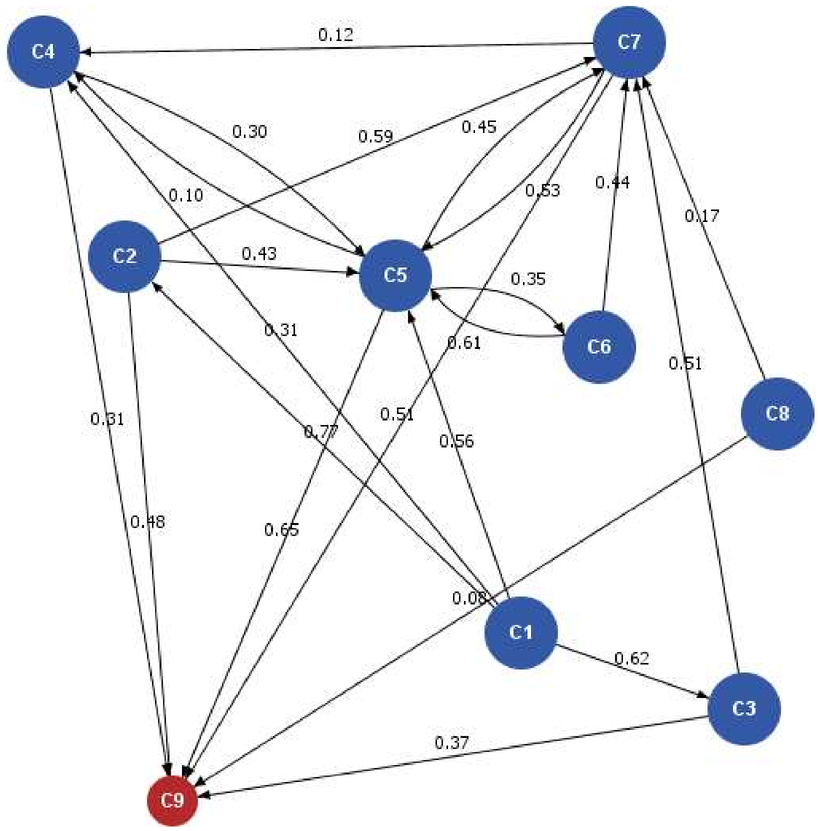


Table 3: Adjustment matrix of the model

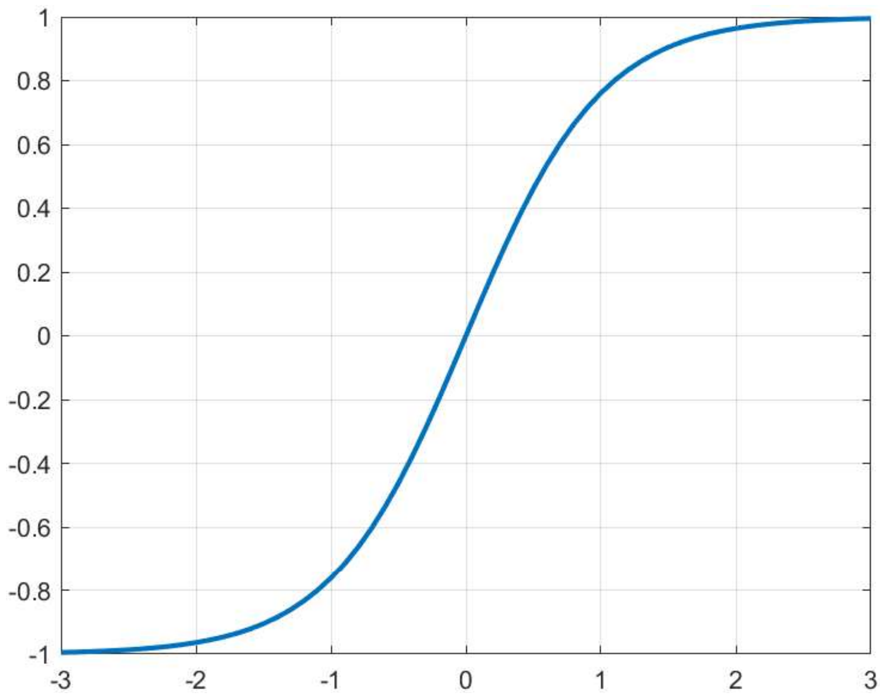
	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	0	0,77	0,62	0,31	0,56	0	0	0	0
C2	0	0	0	0	0,43	0	0,59	0	0,48
C3	0	0	0	0	0	0	0,51	0	0,37
C4	0	0	0	0	0,3	0	0	0	0,31
C5	0	0	0	0,1	0	0,35	0,45	0	0,65
C6	0	0	0	0	0,63	0	0,44	0	0
C7	0	0	0	0,12	0,53	0	0	0	0,41
C8	0	0	0	0	0	0	0,17	0	0,08
C9	0	0	0	0	0	0	0	0	0

For concepts triggering the hyperbolic function is selected. The mathematical formula is given in Equation 2.

$$f_{(x)} = \frac{e^{2x} - 1}{e^{2x} + 1} \qquad (2)$$

The range of x is [-3,3] and represents the interval regarding the state of evaluation for each concept. Correlation between concepts could be positive or negative and multiplied by the weight factor can increase or reduce the affected concept. For that reason, the hyperbolic function is suitable because it takes values between [-1,1]. Negative values arise from the low rating concept and positive values from the high rating concept. In Figure 3 the hyperbolic function diagram is depicted.

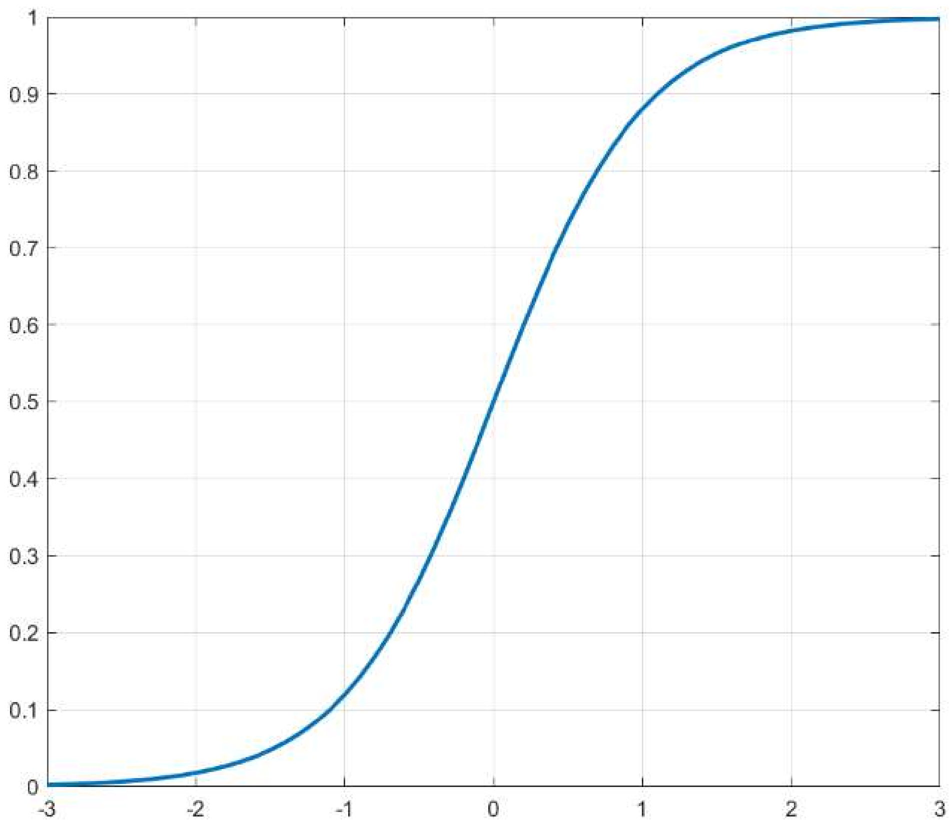
Figure 3: Hyperbolic function curve



For the decision function the Sigmoid curve (Equation 3 and Figure 4) is selected. Sigmoid function can take values into the interval [0,1] for a given output value of HEI-QoS concept.

$$f_{(x)} = \frac{1}{1+e^{-2x}} \qquad (3)$$

Figure 4: Sigmoid function curve

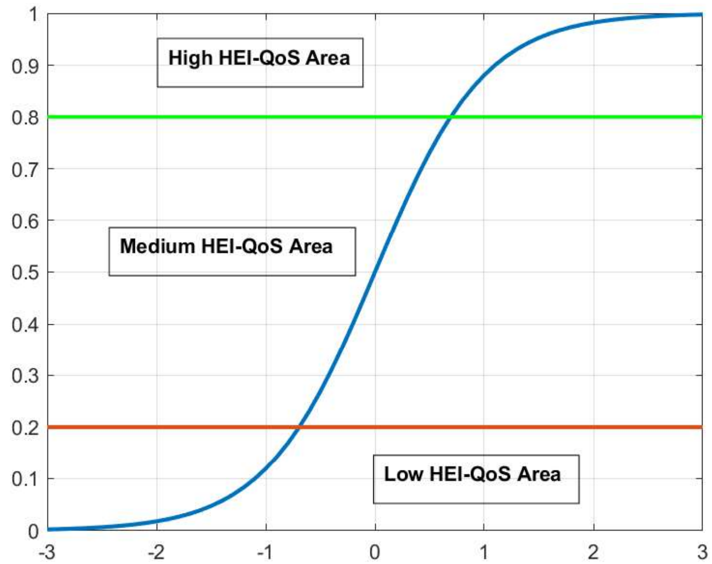


Three areas regarding HEI-QoS are defined:

$$Low\ QoS \quad : 0.00 \leq C_9 \leq 0.20$$
$$Medium\ QoS : 0.20 \leq C_9 \leq 0.80$$
$$High\ QoS \quad : 0.80 \leq C_9 \leq 1.00$$

The evaluation limits together with the sigmoid curve are depicted in Figure 5.

Figure 5: Areas of HEI-QoS



Implementing the FCM model the current state of HEI-QoS can be retrieved according to each parameter (concept) evaluation. The results of model implementation are analysed in the following section.

4. *Results*

For the implementation of the model four main scenarios were selected resulting in three different HEI evaluations of QoS. For each scenario an Input Vector (IV) which represents the concepts' original evaluation taken as an input. After those changes in some of the original concept's values are made resulting in different HEI-QoS ratings. For the analysis, FCM Expert Software (Nápoles *et al.*, 2018) is used.

4.1 Scenario 1

A low-funding case was selected for the first scenario. That is depicted by a zero (0.00) and a negative (-0.50) qualification for concept C1 (Funding). All the other concepts are moderate except C5 (Professor Effectiveness) which is slightly greater (0.40).

The analysis concludes with a high rate of HEI-QoS. Keeping the value of C1 zero and reducing C5 to a negative value (-0.40), resulting in a medium HEI-QoS rate depicting the importance of professors' effectiveness. On the other hand, reducing C5 further (-1.00) and reducing C1 as well (-0.50) leads to a Low HEI-QoS depicting the importance of both concepts (professors and funding) in university operations.

The convergence visualisation of analysis for these cases along with their input vectors are depicted in Figures 6 to 8. Table 4 presents all the scenario 1 analysis results.

Figure 6: The first convergence visualization of scenario 1 with IV = [0.0, 0.2, 0.2, 0.1, 0.40, 0.1, 0.2, 0.05]

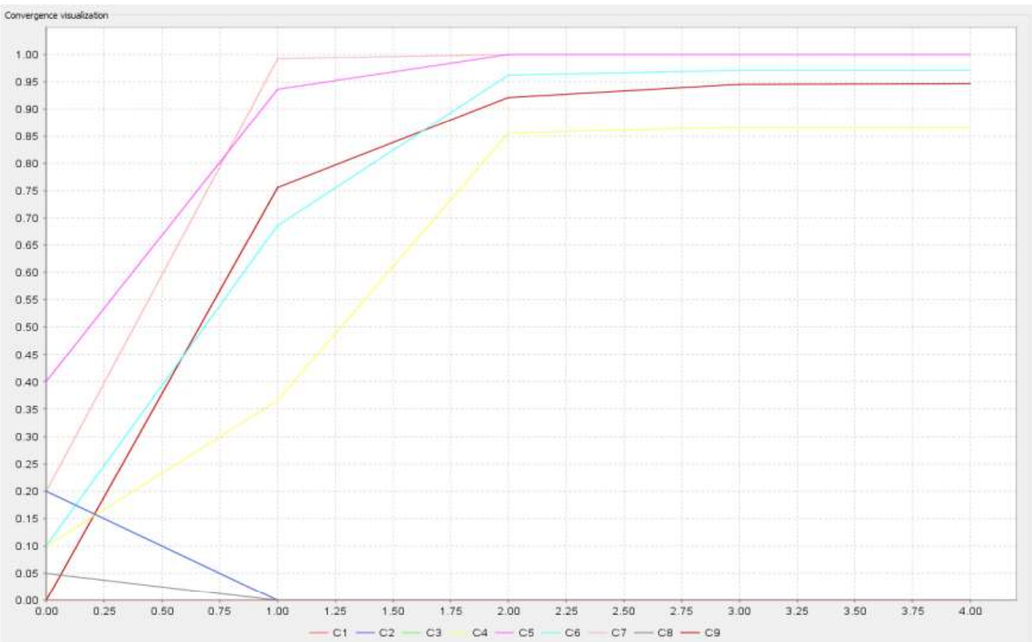


Figure 7: The second convergence visualization of scenario 1 with IV = [0.0, 0.2, 0.2, 0.1, -0.40, 0.1, 0.2, 0.05]

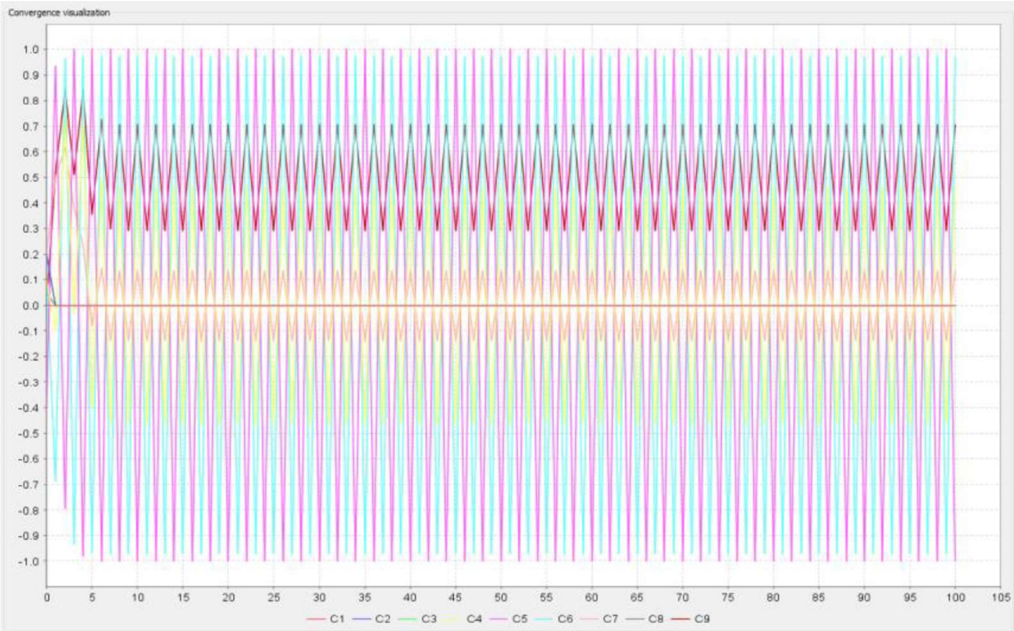


Figure 8: The third convergence visualisation of scenario 1 with IV = [-0.5, 0.2, 0.2, 0.1, -1, 0.1, 0.2, 0.05]

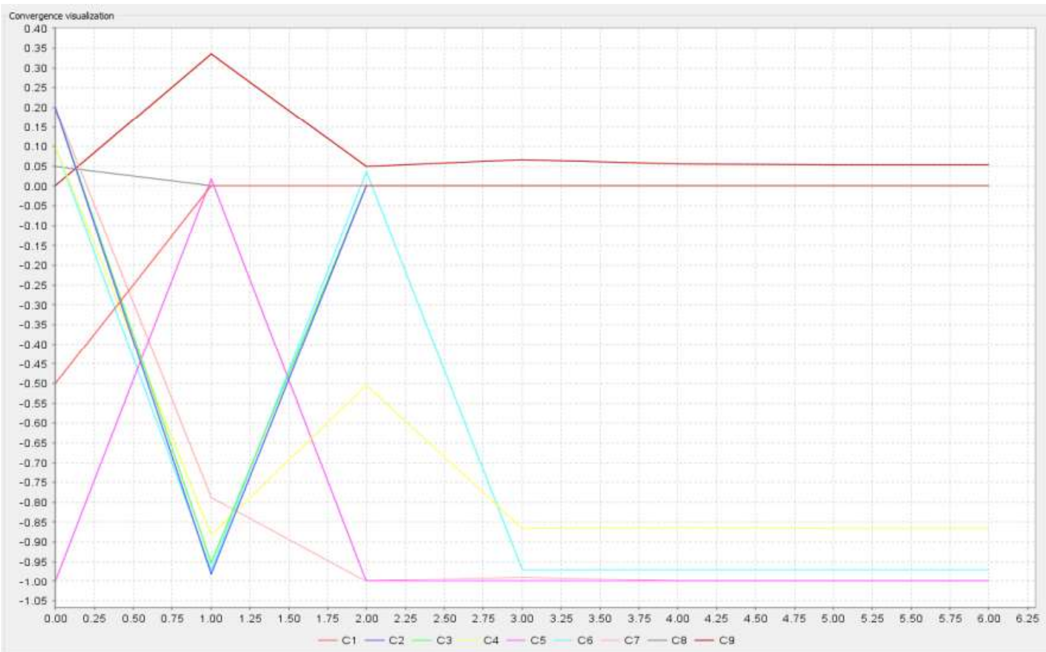


Table 4: Scenario 1 results

	C1	C2	C3	C4	C5	C6	C7	C8	HEI-QoS
S1	0,00	0,20	0,20	0,10	0,40	0,10	0,20	0,05	**High**
S2	0,00	0,20	0,20	0,10	-0,40	0,10	0,20	0,05	**Medium**
S3	-0,50	0,20	0,20	0,10	-1,00	0,10	0,20	0,05	**Low**

4.2 Scenario 2

For the second scenario a high professor's effectiveness was selected, with low ratings in C2, C3 and C8 concepts and the funding as a variable. The first case explores the high performance of professors, laboratories and students' effectiveness and a rather moderate, but positive administrative performance. The analysis resulted in a high HEI-QoS revealing that proper funding could lead eventually to facility upgrades.

The reduction of funding to a negative value (-0.50) keeping all the other concepts the same leads to a low HEI-QoS representing the importance of funding for the evolution and proper operation of HEIs. Without funds, there were no upgrades to facilities leading to the reduction of the other concepts' effect resulting in a low rating HEI.

On the other hand, the reduction of professors' effectiveness to a negative rate of -1 along with moderate funding, keeping all the other concepts the same leads to a medium HEI-QoS. That reveals once again the importance of teaching staff and funding in an HEI operation and reputation. All the results of the analysis are given in Table 5. The convergence visualization of analysis for these cases along with their input vectors are depicted in Figures 9 to 11.

Table 5: Scenario 2 results

	C1	C2	C3	C4	C5	C6	C7	C8	HEI-QoS
S1	0,80	-1,30	-2,00	0,35	2,00	0,80	0,60	-1,30	High
S2	-0,50	-1,00	-2,00	0,30	2,00	0,80	0,60	-1,30	Low
S3	0,00	-1,00	-2,00	0,30	-1,00	0,80	0,60	-1,30	Medium

Figure 9: The first convergence visualization of scenario 2 with IV = [0.8, -1, 3, -2, 0.35, 2, 0.8, 0.6, -1.3]

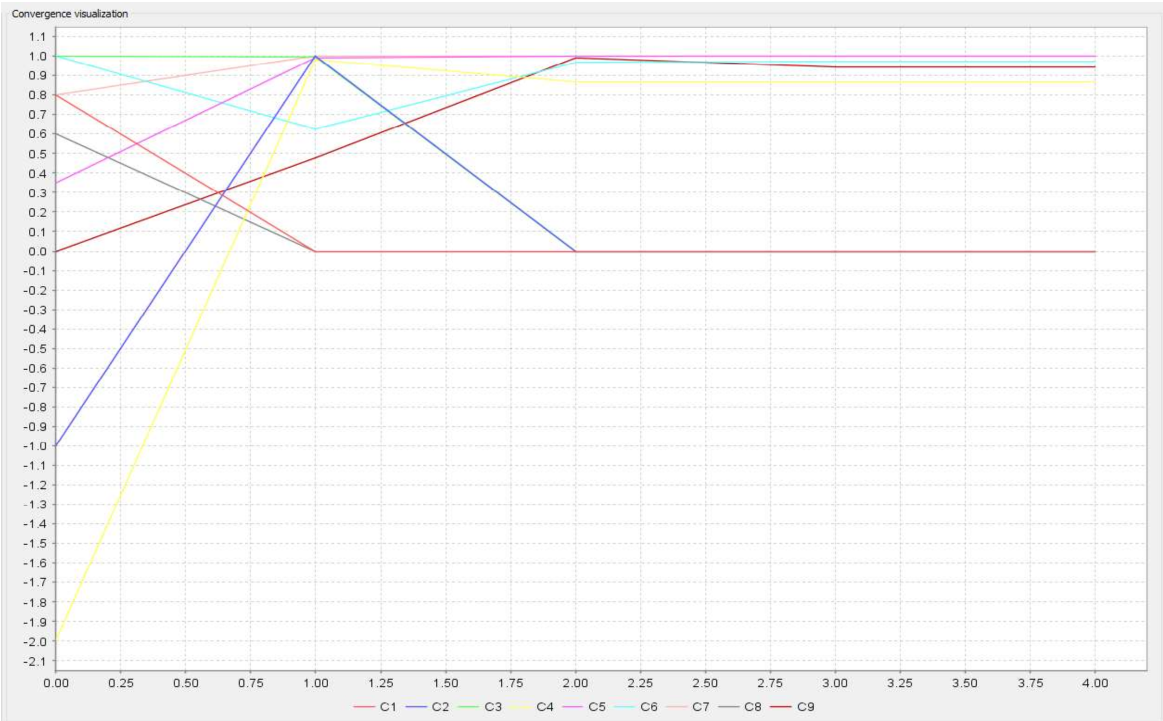


Figure 10: The second convergence visualization of scenario 2 with IV = [-1.5, -1.3, -2, 0.35, 2, 0.8, 0.6, -1.3]

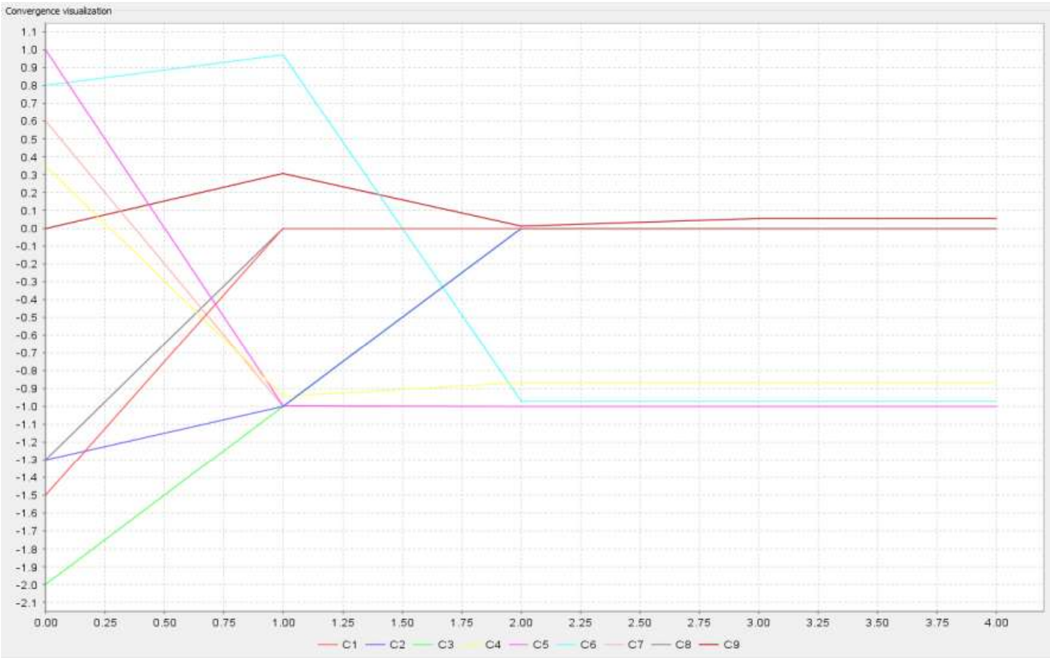


Figure 11: The third convergence visualization of scenario 2 with IV = [-0.0, -1.0, -2, 0.30, -1, 0.8, 0.6, -1]

4.3 Scenario 3

Regarding scenario 3, a very low funding qualification was selected (-3.00) for a university with high location rating (2.00). Also, negative ratings for professors and students' performance along with the administrative staff were included. The results led to a low HEI-QoS as was expected, revealing the minor importance of the location.

Increasing professors' concept to an evaluation of 1.00 leads to a medium HEI-QoS, revealing once again the importance of teaching and research in a HEI qualification. Even with very poor funding if teaching staff produce high-quality work that could lift the HEI rating.

For the third case of scenario 3 a further increment of professors' concept to 3.00. The analysis leads to a medium-quality HEI, depicting the importance of funding in HEI operations. All the results of the analysis are given in Table 6. The convergence visualisation of analysis for these cases along with their input vectors are depicted in Figures 12 to 14.

Table 6: Scenario 3 results

	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*HEI-QoS*
S1	-3,00	0,20	0,10	-1,00	0,00	0,20	-0,40	2,00	***Low***
S2	-3,00	0,20	0,10	-1,00	1,00	0,20	-0,40	2,00	***Medium***
S3	-3,00	0,20	0,10	-1,00	3,00	0,20	-0,40	2,00	***Medium***

Figure 12: The first convergence visualization of scenario 3 with IV = [-3, 0.2 ,0.1, -1, 0.0, 0.2, -0.4, 2]

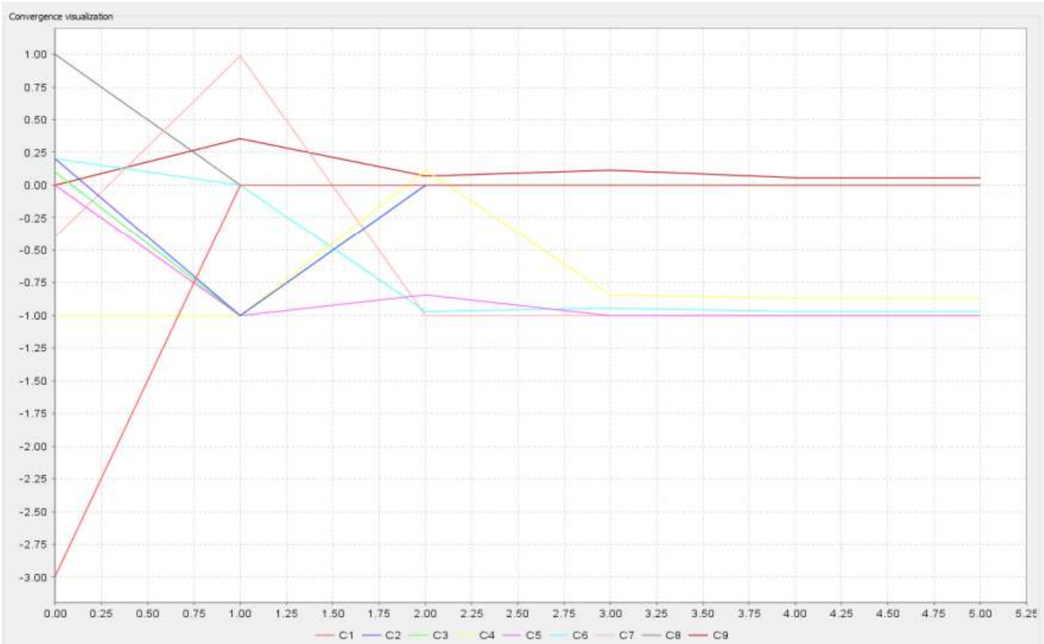


Figure 13: The second convergence visualisation of scenario 3 with IV = [-3, 0.2, 0.1, -1,1, 0.2, -0.4, 2]

Figure 14: The third convergence visualisation of scenario 3 with IV = [-3, 0.2, 0.1, -1, 3, 0.2, -0.4, 2]

4.4 Scenario 4

Finally, scenario 4, investigate the impact of university learning and cultural facilities. For that purpose, a moderate C1 rating was selected (0.00) keeping professors' effectiveness and laboratory equipment at a high level of 1.00. Administrative and students' performance are both above zero ratings (0.50) and the university location is rather moderate (0.80). The three cases of the fourth scenario are depicted in Table 7. The convergence visualisation of analysis for these cases along with their input vectors are depicted in Figures 15 to 17.

Table 7: Scenario 3 results

	C1	C2	C3	C4	C5	C6	C7	C8	HEI-QoS
S1	0,00	-1,20	-1,20	0,50	1,00	1,00	0,50	0,80	***High***
S2	0,00	-3,00	-3,00	0,50	1,00	1,00	0,50	0,80	***Medium***
S3	0,00	-3,00	-3,00	0,50	0,00	1,00	0,50	0,80	***Low***

Analysis results lead to a High HEI-QoS even with rather low rating facilities if professors and laboratory equipment are in high evaluation ratings.

Reducing facilities concept rating further to -3 (both for learning and cultural) keeping all other ratings unchanged resulting in a medium rate HEI-QoS. Notice that the professor's high rate is very important for the overall HEI operation.

Keeping all concept ratings, the same as case 2 (S2) and reducing professors' effectiveness to 0.00 (a moderate rating) resulted in a low HEI-QoS which confirms all the previous analyses regarding teaching staff importance in Higher Education.

Figure 15: The first convergence visualisation of scenario 4 with IV = [0.0, -1.2, -1.20, 0.5, 1.0, 1.0, 0.50, 0.80]

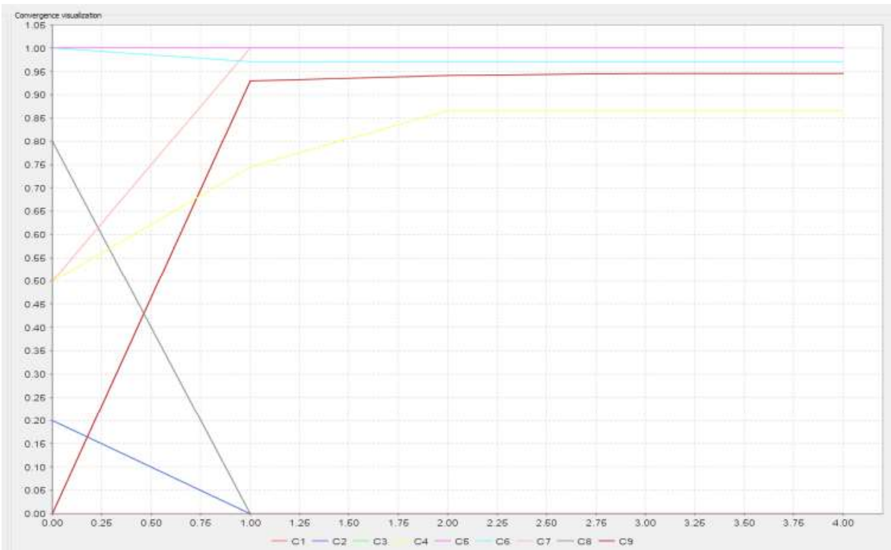
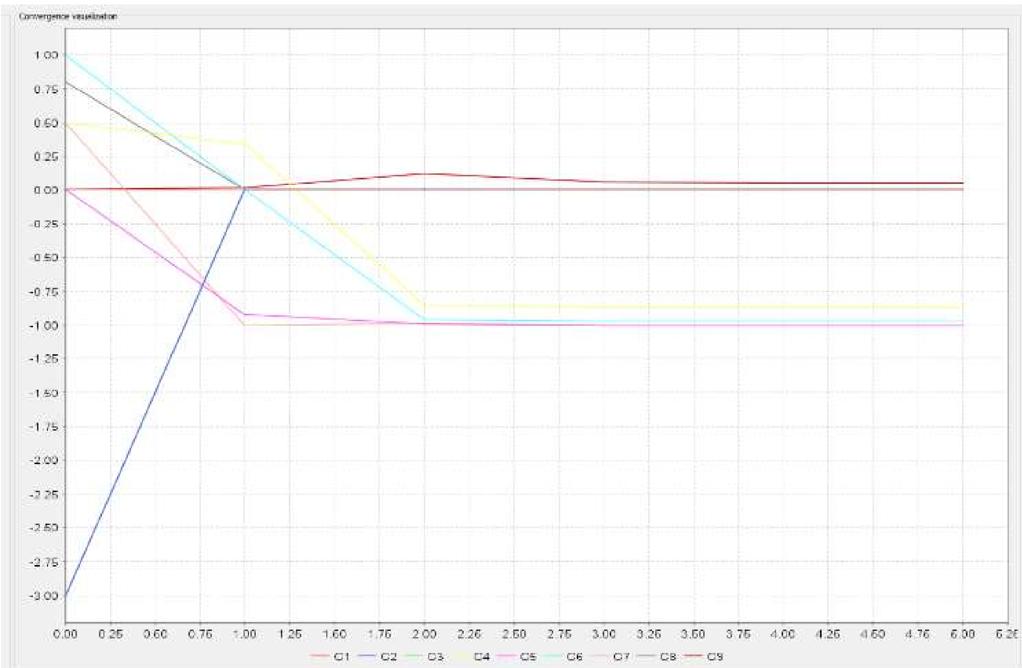


Figure 16: The second convergence visualisation of scenario 4 with IV = [0.0, -3.0, -3.0, 0.5, 1.0, 1.0, 0.50, 0.80]

Figure 17: The third convergence visualisation of scenario 4 with IV = [0.0, -3, -3, 0.5, 0.0, 1, 0.50, 0.80]



5. Conclusions

FCMs offer a valuable approach to understanding complex systems by capturing the interplay between variables. Their applications continue to expand, making them an indispensable tool for decision-makers. The modelling of systems based on their concepts can take on any level of detail, mirroring the numerous interactions between the various factors into play.

This paper presents a novel approach to a systematic and effective analysis and evaluation of the QoS of a complex system, such as a university, employing an FCM model to estimate a Quality-of-Service factor regarding HEI evaluation. Using the technique of Fuzzy Cognitive Maps, an outline of the importance and the interactions between various factors affecting the institutions' QoS was designed and then used to estimate its effectiveness. The analysis of the results revealed the importance of Professors in HEI operations. As expected, the effectiveness of teaching and research operations is strictly combined with adequate funding, laboratory equipment and university facilities. HEI location affects QoS in a minor way although it might play a part in the selection of HEI by the students for their studies.

The application of the model confirms its validity, offering results, such that the optimised values can then be used as benchmarks by the HEIs' policymakers. The values used, formed by realistic assumptions based on experts' opinions, provided results that hint at the possibilities offered by this approach. High-quality HEIs are characterised by good Professors and facilities combined with adequate funding. On the other hand, moderate funding combined with high-level facilities and teaching staff leads to a medium-level HEI evaluation. All cases with low Professor ratings result in a low-level HEI even with sufficient institute funding. Note that a very low funding rating combined with high-level teaching performance leads to a medium rating HEI, reaffirming the importance of professors' role in HEI operations.

An analysis of the sensibility of the model to variations of the values used confirmed that these can be further elaborated and optimised by using tools from Artificial Intelligence and Optimization Theory such as Learning Algorithms, Genetic Algorithms, and Neural Networks, among others. Based on well-processed data, the concept can form a valuable tool for the improvement of Universities' operations and the degree of satisfaction of stakeholders involved. Future work should thus build on the promise for FCMs with emerging hybrid models and increased data availability. Research should focus on robustness and scalability.

References

Adina-Petruta Pavel, (2015), "Global university rankings - a comparative analysis", Elsevier, Procedia Economics and Finance, vol.26, p.p. 54 – 63, DOI: 10.1016/S2212-5671(15)00838-2.

Aguilar J. (2005), "A survey about Fuzzy Cognitive maps papers", International Journal of Computational Cognition Volume 2, June 2005.

Apostolopoulos, I.D., Groumpos, P.P. and Apostolopoulos, D.J. (2021), "Advanced fuzzy cognitive maps: state-space and rule-based methodology for coronary artery disease detection" Inter. Journal of Biomedical Physics & Engineering Express, Volume 7, Issue 4, pp.o45007, IOP Publishing.

Axelrod R. (1976) “Structure of Decision: The Cognitive Maps of Political Elites.” Princeton University Press DOI 10.2307/2616237.

Baporikar, N. (2021), “Stakeholder approach for quality higher education,” in Research Anthology on Preparing School Administrators to Lead Quality Education Programs. Pennsylvania: IGI Global., 2021, 1664–1690. DOI 10.4018/978-1-7998-3438-0.ch075.

Barbrook-Johnson, P., Penn, A.S. (2002), “Fuzzy Cognitive Mapping. In: Systems Mapping”. Palgrave Macmillan, Cham. DOI 10.1007/978-3-031-01919-7_6.

Biggs, N., Lloyd, E. and Wilson, R. (1986), “Graph Theory,” Oxford University Press, pp. 1736-1936.

Dias Sofia B. *et. al*. (2015) “Fuzzy cognitive mapping of LMS users’ Quality of Interaction within higher education blended-learning environment”, Expert Systems with Applications, Vol.42, ELSEVIER, 2015, Pages 7399-7423, DOI 10.1016/j.eswa. 2015.05.048.

ECOLHE project, (2023), “The European Higher Education Area Facing The Digital Challenge”, Erasmus+ KA2-Strategic Partnerships in the field of Education (2020-1-IT02-KA203-079176).DOI: 10.26220/eco.4512.

Estrada-Real, A.C., Cantu-Ortiz, F.J. (2022), “A data analytics approach for university competitiveness: the QS world university rankings.”, Int J Interact Des Manuf 16, p.p. 871–891 (2022). DOI: 10.1007/s12008-022-00966-2.

European Commission. "Digital Education Action Plan (2021-2027)".

Felix, G., Nápoles, G., Falcon, R., Froelich, W., Vanhoof, K., & Bello, R. (2019). "A review on methods and software for Fuzzy Cognitive Maps". Artificial Intelligence Review, 52(3), 1707–1737. DOI 10.1007/s10462-017-9575-1.

Gauchy, A. L., "Recherche sur les polyèdres - premier mémoire," Journal de l'Ecole Polytechnique 9, vol. 16, pp. 66-86, 1813.

Glykas M. (2010), "Fuzzy Cognitive Maps", Studies in Fuzziness and Soft Computing, Volume 247, Springer-Verlag Berlin Heidelberg.

Groumpos, P. P., and Anninou, A.P. (2012), "A theoretical mathematical modeling of Parkinson's disease using Fuzzy Cognitive Maps," Proc. of 12th International Conference on Bioinformatics and Bioengineering (BIBE), pp 677 – 682.

Harvey, L., and Askling, B. (2003), "Quality in higher education," in The Dialogue Between Higher Education Research and Practice, ed. R. Begg (Berlin: Springer), 69–83. DOI 10.1080/ 13538320308164.

Helfgott, A., Lord, S., Bean, N., Wildenberg, M., Gray, S., Gray, S., Vervoort, J., Kok, K., & Ingram, J. (2015). "Clarifying fuzziness: Fuzzy Cognitive Maps, neural networks and system dynamics models in participatory social and environmental decision-aiding processes". Processes EUFP7 TRANSMANGO Working Paper 1.

Jacek Pietrucha, (2018), “Country-specific determinants of world university rankings”, Springer Scientometrics, 2018, pp. 1129-1139, DOI: 10.1007/s11192-017-2634-1.

Jetter A. J., Kok K., (2014), “Fuzzy Cognitive Maps for futures studies—A methodological assessment of concepts and methods”, Futures, Vol 61, ELSEVIER, DOI 10.1016/j.futures.2014.05.002.

Kosko B. (1986), “Fuzzy cognitive maps”, International Journal of Man-Machine Studies, 24, 65–75.

Kosko B. (1993). “Adaptive inference in fuzzy knowledge networks”, Readings in Fuzzy Sets for Intelligent Systems, 1993, Pages 888-891. DOI 10.1016/B978-1-4832-1450-4.50093-6.

L’Huillier, (1861), S. A. J., “Memoire sur le Polyedrometrie,” Annales de Mathematiques 3, pp. 169-189.

Moed, H.F. (2017), “A critical comparative analysis of five world university rankings.”, Scientometrics 110, p.p. 967–990. DOI: 10.1007/s11192-016-2212-y.

Mpelogianni, V. G. & Groumpos, P. P. (2018), “Re-approaching fuzzy cognitive maps to increase the knowledge of a system”, Intern. Journal AI & SOCIETY, pp.1-14.

Mustapha S. M. *et al.* (2010), “Factors influencing classroom participation: a case study of Malaysian undergraduate students”, Procedia - Social and Behavioral Sciences Vol. 9, 2010, Pages 1079-1084, ELSEVIER. DOI 10.1016/j.sbspro.2010.12.289.

Nápoles G., Leon Espinosa M., Grau I., and Vanhoof K. (2018), “FCM expert: Software tool for scenario analysis and pattern classification based on fuzzy cognitive maps.” International Journal on Artificial Intelligence Tools 27.07: 1860010. DOI 10.1142/S0218213018 600102.

Papageorgiou, E.I., Stylios, C.D., Groumpos, P.P. (2003), “Fuzzy cognitive map learning based on nonlinear Hebbian rule”, Lecture Notes in Computer Science, vol. 2903, pages.256–268, DOI 10.1007/978-3-540-24581-0_22.

Papageorgiou E.I. (2014), “Fuzzy Cognitive Maps for Applied Sciences and Engineering from Fundamentals to Extensions and Learning Algorithms”, Springer, ISBN 978-3-642-39739-4 (eBook), DOI 10.1007/978-3-642-39739-4.

Purnomo M., Anugerah A., Dewipramesti B. (2020), “Sustainable Supply Chain Management Framework in a Higher Education Laboratory Using Intuitionistic Fuzzy Cognitive Map”, Journal of Industrial Engineering and Management. DOI 10.3926/jiem.3204.

Raghuram, S., Hill, N. S., Gibbs, J. L., and Maruping, L. M. (2019), “Virtual work: bridging research clusters”. Acad. Manag. Ann. 13, 308–341. DOI 10.5465/annals.2017.0020.

Rieckmann, M. (2012), “Future-oriented higher education: which key competencies should be fostered through university teaching and learning?”. Futures 44, 127–135. DOI: 10.1016/j.futures.

Seymour, D. T. (1992), “On Q: Causing Quality in Higher Education”. New York, NY: Macmillan Publishing Company. 100 Front St., Riverside, NJ 08075- 7500.

Stach Wojciech, Kurgan Lukasz, Pedrycz Witold, Reformat Marek, (2005), “Genetic learning of fuzzy cognitive maps”, Fuzzy Sets and Systems, Volume 153, Issue 3, 1 August 2005, Pages 371-401.

Stach W., Kurgan L. and Pedrycz W., (2007), “Parallel Learning of Large Fuzzy Cognitive Maps,” 2007 International Joint Conference on Neural Networks, Orlando, FL, USA, 2007, pp. 1584-1589. DOI: 10.1109/IJCNN.2007.4371194.

Stach Wojciech, Kurgan Lukasz, and Pedryc Witold, (2007), “A Survey of Fuzzy Cognitive Map Learning Methods”.

Vergini, E.S. and Groumpos, P.P., (2018), “Modeling nearly Zero Energy Building using new equations and separating concepts on Fuzzy Cognitive Maps”- Elsevier, IFAC-PapersOnLine, Volume 51, Issue 30, pp. 709-714, 2018.