

CONTROL OF EDUCATIONAL PROCESSES AND ASSESSMENT OF QUALITY IN HIGHER EDUCATION INSTITUTIONS BASED ON FUZZY SET THEORY

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Abstract

This study examines the approach based on fuzzy set theory for controlling educational processes and assessing the quality of education in higher education institutions. Fuzzy set theory is an effective approach for identifying and evaluating uncertainties in educational processes, playing a key role in overcoming the limitations of traditional assessment systems. This approach helps reduce subjectivity in the educational process, enables more accurate evaluation of students' knowledge and skills, and serves as an effective tool for improving the quality of education.

Keywords: Higher education, education quality, fuzzy set theory, uncertainty management, dynamic assessment system, fuzzy sets, mathematical modeling, knowledge assessment.

Introduction

The quality of education in higher education institutions (HEIs) is considered a crucial factor in national development. However, monitoring and assessing the quality of educational processes in HEIs is a complex task due to numerous influencing factors. Traditional assessment methods often fail to capture the subtle and complex aspects of education. This article explores the application of fuzzy set theory as an innovative approach to monitoring and evaluating the quality of education in HEIs. Fuzzy set theory, originally proposed by Zadeh¹ as

¹ Zadeh, L. A. (1965). Fuzzy sets. Information and Control, 8(3), 338-353.

an effective approach to identifying and evaluating uncertainties in the educational process, was later developed by Ross² and others in the fields of engineering and education.

Methodology Related to the Topic. The data were primarily collected based on the following key performance indicators (KPIs):

1. **Student Outcomes:** This indicator includes information such as students' grades, attendance, graduation rates, and performance across various subjects. Data were gathered from the HEMIS information system and other university information systems through the analysis of academic records, exam results, and student evaluations.
2. **Faculty Qualifications:** The academic degrees, work experience, research activity, and publications of faculty members were examined. These data were obtained from university administrations, internal KPI programs, research centers, and open data sources.
3. **Research Activities:** The scientific research activities of HEIs, including research projects, grants, academic publications, and patents, were considered. This information was collected from scientific publications and university research departments.
4. **Administrative Effectiveness:** This indicator assessed university management processes, financial condition, infrastructure, and the efficient use of resources. For this purpose, documents from university administrations, financial reports, and audit results were analyzed.

Surveys: During the data collection process, surveys were conducted. These were distributed among students, faculty members, and university administrators. The survey method allowed for identifying subjective opinions and gathering additional qualitative data.

Academic Records: Academic records and reports served as a primary data source. These documents reflect student and faculty activities, curricula, assessment systems, and overall university performance. The records were carefully analyzed and categorized into indicators, then integrated into the fuzzy sets system.

² Ross, T. J. (2004). Fuzzy logic with engineering applications. John Wiley & Sons.

Statistical Data: Statistical data were also used in the data collection process. These included information on student demographics, attendance, graduation rates, and other key metrics. The data were obtained from the HEMIS system and the statistics departments of university KPI systems.

Data Analysis: The collected data were processed using analysis methods based on fuzzy set theory. For each KPI, linguistic variables and membership functions were identified, and final evaluations were calculated using a fuzzy inference system.

Application of Fuzzy Set Theory. Fuzzy set theory was utilized to model uncertainty and vagueness in educational assessment. Fuzzy logic systems were developed to analyze the collected data.

The main stages included the following:

Identification of Linguistic Variables: For various indicators, linguistic variables such as *high quality*, *medium quality*, and *low quality* were defined³.

Membership Functions: For each linguistic variable, membership functions were developed, allowing the determination of the degree to which the indicators belong to these variables.

Fuzzy Inference System: A system was designed to aggregate membership values and provide a comprehensive evaluation of education quality⁴.

Identification of Linguistic Variables: Linguistic variables are one of the key elements of a fuzzy system, enabling the mathematical representation of vague and subjective concepts. In this study, the following linguistic variables were identified:

- Student Outcomes: High, Medium, Low
- Faculty Qualifications: High, Medium, Low
- Research Activities: High, Medium, Low
- Administrative Effectiveness: High, Medium, Low

³ Chen va Lee (1999). Evaluating students' learning achievement using fuzzy membership functions and fuzzy rules

⁴ Nabel Algshat (2024). Evaluating Students' Academic Progress in the Role of Fuzzy Logic

For each linguistic variable, corresponding membership functions were developed.

Membership Functions: Membership functions are mathematical functions that represent full or partial membership for each linguistic variable. In this study, triangular⁵ and trapezoidal membership functions were used, as they are considered simple and effective⁶.

Below are examples of membership functions for each KPI:

1. Student Outcomes:

$$\text{High: } \mu_{\text{High}}(x) = \begin{cases} 0 & \text{agar } x \leq 70 \\ \frac{x-70}{30} & \text{agar } 70 < x < 100 \\ 1 & \text{agar } x \geq 100 \end{cases}$$

$$\text{Medium: O'rta: } \mu_{\text{Medium}}(x) = \begin{cases} 0 & \text{agar } x \leq 40 \\ \frac{x-40}{30} & \text{agar } 40 < x < 70 \\ \frac{100-x}{30} & \text{agar } 70 \leq x < 100 \\ 0 & \text{agar } x \geq 100 \end{cases}$$

$$\text{Low:Past: } \mu_{\text{Low}}(x) = \begin{cases} 1 & \text{agar } x \leq 40 \\ \frac{70-x}{30} & \text{agar } 40 < x < 70 \\ 0 & \text{agar } x \geq 70 \end{cases}$$

2. Faculty Qualifications:

$$\text{High: } \mu_{\text{High}}(x) = \begin{cases} 0 & \text{agar } x \leq 10 \\ \frac{x-10}{20} & \text{agar } 10 < x < 30 \\ 1 & \text{agar } x \geq 30 \end{cases}$$

$$\text{Medium: } \mu_{\text{Medium}}(x) = \begin{cases} 0 & \text{agar } x \leq 5 \\ \frac{x-5}{15} & \text{agar } 5 < x < 20 \\ \frac{30-x}{10} & \text{agar } 20 \leq x < 30 \\ 0 & \text{agar } x \geq 30 \end{cases}$$

⁵ Zadeh, L. A. (1975). *The concept of a linguistic variable and its application to approximate reasoning—I*. Information sciences, 8(3), 199-249.

⁶ Zimmermann, H.-J. (2001). *Fuzzy Set Theory—and Its Applications*. Springer Science & Business Media.

$$\text{Low: } \mu_{\text{Low}}(x) = \begin{cases} 1 & \text{agar } x \leq 5 \\ \frac{20-x}{15} & \text{agar } 5 < x < 20 \\ 0 & \text{agar } x \geq 20 \end{cases}$$

Fuzzy Inference System: The fuzzy inference system operates based on membership functions⁷ and linguistic rules⁸. This system receives input data and converts them into fuzzy membership values⁹.

Then, these values are processed based on linguistic rules, and output values are generated. Below are the main stages of the fuzzy inference system:

Fuzzification: Converting input data into fuzzy membership values.

Rule Application: Applying linguistic rules. For example, if student outcomes are high and faculty qualifications are high, then the quality of education is evaluated as high.

Aggregation: Combining the results of multiple rules.

Defuzzification: Converting fuzzy results into precise values.

Application Results: Through this approach, the quality of education was assessed more accurately and realistically compared to traditional evaluation methods. The results showed that the fuzzy logic system allows for capturing uncertainty and subjectivity in assessing education quality. This approach helped facilitate effective decision-making in monitoring and evaluating educational processes.

The application of fuzzy set theory significantly assisted HEI administrators in making more precise decisions regarding improvements in education quality. Moreover, this approach enabled the identification of problems related to education quality and the implementation of effective measures to address them.

Results:

The application of fuzzy set theory enabled a more nuanced understanding of education quality in higher education institutions (HEIs). The fuzzy logic system allowed for the inclusion of subjectivity and uncertainty in educational

⁷ Mendel J. M. *Uncertain Rule-Based Fuzzy Logic Systems: Introduction and New Directions*. – Prentice Hall PTR, 2001. – 552 p.

⁸ Wang L. X., Mendel J. M. Generating fuzzy rules by learning from examples // *IEEE Transactions on Systems, Man, and Cybernetics*. – 1992. – Vol. 22, no. 6. – P. 1414–1427.

⁹ Karnik N. N., Mendel J. M. Operations on type-2 fuzzy sets // *Fuzzy Sets and Systems*. – 2001. – Vol. 122, no. 2. – P. 327–348.

assessments, offering a more flexible and realistic evaluation framework. The main results are as follows:

- **Improved Accuracy:** The fuzzy approach provided a more accurate assessment of education quality compared to traditional methods.
- **Transparent Evaluation:** The system integrated various indicators and presented a clear and transparent view of education quality.
- **Enhanced Decision-Making:** The results gave HEI administrators better opportunities to make informed decisions and implement targeted improvements in specific areas.

A model and software code for assessing education quality using fuzzy logic can be developed using the Python programming language.

To visualize the outcome of education quality through membership functions, we use the skfuzzy library in Python. Through graphical representation of the results, the output of the fuzzy system can be clearly demonstrated. Below is an example of how the results can be represented through membership functions.

```
import numpy as np
import skfuzzy as fuzz
from skfuzzy import control as ctrl
import matplotlib.pyplot as plt

# Define input variables
student_outcome = ctrl.Antecedent(np.arange(0, 101, 1),
'student_outcome')
faculty_qualification = ctrl.Antecedent(np.arange(0, 101, 1),
'faculty_qualification')
research_activity = ctrl.Antecedent(np.arange(0, 101, 1),
'research_activity')
administrative_efficiency = ctrl.Antecedent(np.arange(0, 101, 1),
'administrative_efficiency')
# Define output variable
education_quality = ctrl.Consequent(np.arange(0, 101, 1),
'education_quality')
# Define membership functions
```

```

student_outcome['low'] = fuzz.trimf(student_outcome.universe, [0, 0, 50])
student_outcome['medium'] = fuzz.trimf(student_outcome.universe, [30,
50, 70])
student_outcome['high'] = fuzz.trimf(student_outcome.universe, [50, 100,
100])
faculty_qualification['low'] = fuzz.trimf(faculty_qualification.universe, [0,
0, 50])
faculty_qualification['medium'] = fuzz.trimf(faculty_qualification.universe,
[30, 50, 70])
faculty_qualification['high'] = fuzz.trimf(faculty_qualification.universe,
[50, 100, 100])
research_activity['low'] = fuzz.trimf(research_activity.universe, [0, 0, 50])
research_activity['medium'] = fuzz.trimf(research_activity.universe, [30,
50, 70])
research_activity['high'] = fuzz.trimf(research_activity.universe, [50, 100,
100])
administrative_efficiency['low'] =
fuzz.trimf(administrative_efficiency.universe, [0, 0, 50])
administrative_efficiency['medium'] =
fuzz.trimf(administrative_efficiency.universe, [30, 50, 70])
administrative_efficiency['high'] =
fuzz.trimf(administrative_efficiency.universe, [50, 100, 100])
education_quality['low'] = fuzz.trimf(education_quality.universe, [0, 0, 50])
education_quality['medium'] = fuzz.trimf(education_quality.universe, [30,
50, 70])
education_quality['high'] = fuzz.trimf(education_quality.universe, [50, 100,
100])

```

Define rules

```

rule1 = ctrl.Rule(student_outcome['high'] & faculty_qualification['high'] &
research_activity['high'] & administrative_efficiency['high'],
education_quality['high'])
rule2 = ctrl.Rule(student_outcome['medium'] &
faculty_qualification['medium'] & research_activity['medium'] &
administrative_efficiency['medium'], education_quality['medium'])

```

```
rule3 = ctrl.Rule(student_outcome['low'] & faculty_qualification['low'] &
research_activity['low'] & administrative_efficiency['low'],
education_quality['low'])
```

```
# Create fuzzy control system
```

```
education_quality_ctrl = ctrl.ControlSystem([rule1, rule2, rule3])
```

```
education_quality_sim =
```

```
ctrl.ControlSystemSimulation(education_quality_ctrl)
```

```
# Set input values
```

```
education_quality_sim.input['student_outcome'] = 75
```

```
education_quality_sim.input['faculty_qualification'] = 85
```

```
education_quality_sim.input['research_activity'] = 90
```

```
education_quality_sim.input['administrative_efficiency'] = 80
```

```
# Compute the result
```

```
education_quality_sim.compute()
```

```
# Print the result
```

```
print(f"Education Quality:
```

```
{education_quality_sim.output['education_quality']}")
```

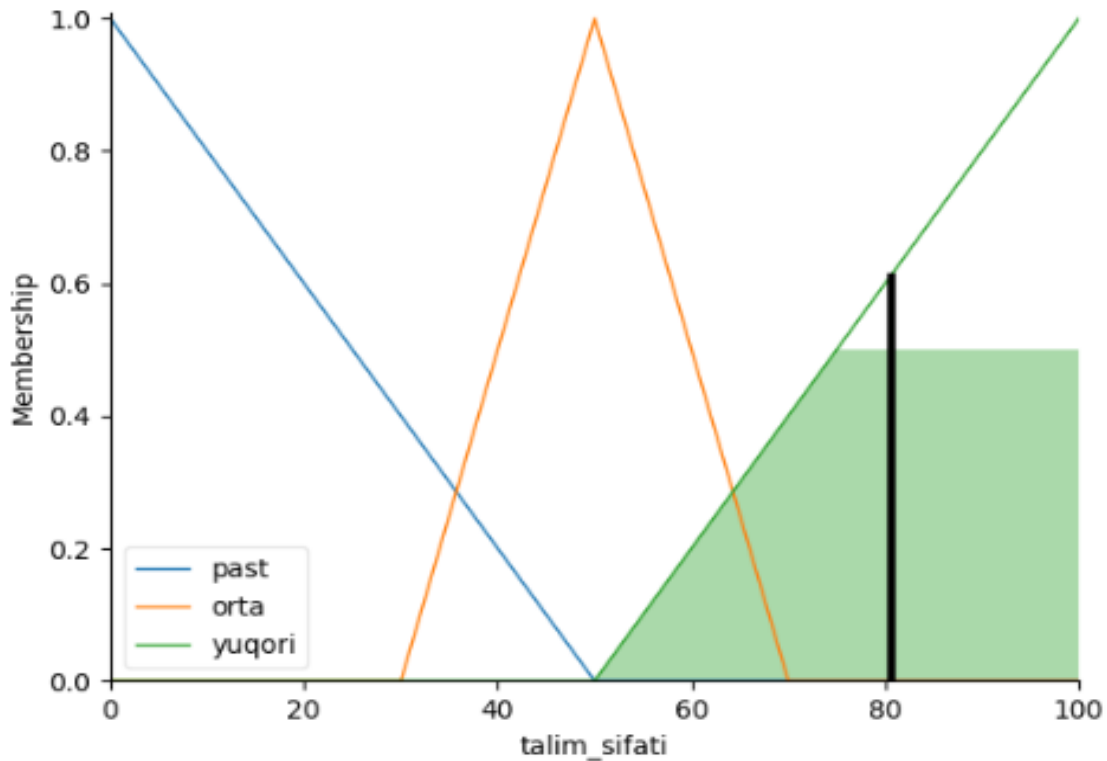
```
# Visualize the result
```

```
education_quality.view(sim=education_quality_sim)
```

```
plt.show()
```

Education Quality: 80.55555555555556

This result shows that, based on the given input levels, the overall education quality is approximately **80.56**, according to the fuzzy logic system.



1. Explanation of the Code:
2. Input Variables: student_outcome, faculty_qualification, research_activity, and administrative_efficiency – these variables represent student performance, faculty qualifications, research activity, and administrative efficiency, respectively. Each can take values in the range from 0 to 100.
3. Output Variable: education_quality – this represents the overall quality of education in a higher education institution (HEI).
4. Membership Functions: For each input and output variable, membership functions for *low*, *medium*, and *high* have been defined. These functions allow fuzzy interpretation of student performance, faculty qualification, research activity, and administrative efficiency.
5. Rules: Three main rules are defined:
6. If all input variables are *high*, then the education quality is *high*.
7. If all input variables are *medium*, then the education quality is *medium*.
8. If all input variables are *low*, then the education quality is *low*.

9. Fuzzy Control System: The rules are combined using `ctrl.ControlSystem` and simulated using `ctrl.ControlSystemSimulation`.

10. Input Values: Specific input values are entered, and the system computes the output result.

11. Output Results: The output result is printed to the screen and visualized graphically.

This code automates the evaluation of education quality using fuzzy logic and provides graphical representation of the results. You can customize the code to fit your needs by modifying it or adding additional rules or variables.

Conclusion

The approach based on fuzzy set theory overcomes several limitations of traditional evaluation methods. By incorporating linguistic variables and membership functions, the system is able to capture the complexity and subjectivity present in educational assessments. This approach proved particularly effective in contexts where quantitative data is limited, as it allows for the inclusion of qualitative aspects.

The study also emphasized the importance of continuously improving the fuzzy logic system. As educational processes evolve, the system must be updated to reflect new complexities and emerging challenges.

This research demonstrated the potential of fuzzy set theory in enhancing the monitoring and evaluation of education quality in higher education institutions. The approach provides a robust framework that embraces the complexity of education and enables more accurate and comprehensive evaluations. By using fuzzy logic, HEIs can improve decision-making processes, ultimately leading to higher educational standards and better student outcomes.

Future research should focus on expanding the scope of KPI indicators and integrating fuzzy set theory with other advanced analytical methods.

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