Construction and verification of the emerging engineering talents evaluation model based on fuzzy mathematics theory

Ze Zhang¹, Chunjiang Li¹,², Xiaojun Ma¹, * and Desheng Liu¹

¹ School of Economics and management, Jiamusi University, Jiamusi, Heilongjiang, 154007, China
² Dean’s Office, Mudanjiang Normal University, Mudanjiang, Heilongjiang, 157011, China
Corresponding author’s e-mail: mjzx2009phd@jmsu.edu.cn
Corresponding author’s ORCID: https://orcid.org/0000-0002-2750-0676
* These authors contributed equally

Abstract. In view of the present situation of cultivating innovation and entrepreneurship ability of engineering talents in local colleges and universities, it is necessary to perfect the evaluation mechanism of emerging engineering talents cultivation, and design the evaluation standard system of supporting the conditions of innovation and entrepreneurship education for college students. Based on the evaluation standard, the Fuzzy Analytic Hierarchy Process (FAHP) theory is used to establish the mathematical model and evaluation model of the evaluation system of college students' innovation and entrepreneurship education condition support under the emerging engineering background. The results show that the established model has universality, accuracy and practicability, and provides technical support for the evaluation of emerging engineering talents, so as to form a closed loop of quality engineering, constantly improve the quality of emerging engineering talents cultivation, and provide talent support for national and regional innovation-driven development.

1. Introduction
The emerging round of industrial revolution and technological innovation has put forward higher requirements for the engineering concept, engineering rigour, critical thinking and the ability to solve complex problems of engineering technicians in the future. Therefore, the government actively promotes emerging engineering research and practice projects, and guides universities to keep up with the pace of higher engineering education in the world through project classification, so that engineering education can follow, run and lead. China's higher engineering education has a complete engineering education system, with the number of majors and students accounting for nearly 1/3 of the country’s higher education [1-2]. However, there are still some practical manifestations in higher engineering education, such as maladjustment of concept, talent structure, knowledge system and training mode. The evaluation of innovation and entrepreneurship training mode of emerging engineering talents should conscientiously implement the requirements of the Overall Plan for Deepening Education Evaluation Reform in the emerging Era issued by the State Council, carry out the fundamental task of creating people by virtue, follow the law of education, establish a baton through the evaluation system, overcome the shortcomings of innovation and entrepreneurship education for engineering talents, strengthen process evaluation, explore value-added evaluation, and
use information technology to enhance the scientific, professional and objective evaluation. Therefore, it can form an evaluation system of the training mode of innovation and entrepreneurship education for emerging engineering talents, which is full of the characteristics of the times, highlight the characteristics of China's engineering education and reflect the world level [3-4].

In order to improve the comprehensive ability, international vision, management ability and practical ability of engineering students, China has launched an innovation and entrepreneurship education program for college students, which have been actively carried out in various colleges and universities. The program is flexible in form and rich in content. The program drives innovation and entrepreneurship of college students, science and technology incubation base, maker space and other innovation and entrepreneurship modes, which effectively promotes the improvement of talent training quality and increases the employment rate [5]. Most local colleges and universities are located in non-central cities, and there is still a gap between the conditions of running schools, faculty, teaching reform, quality assurance and characteristic development and those of Project 211, Project 985 and Double First-class colleges and universities [6]. In 2017, the Ministry of Education implemented an emerging engineering research and practice project. Under the background of emerging engineering, the reform and development of engineering education in local colleges and universities are facing opportunities and challenges, define the orientation of the school, arrange discipline around the regional industrial development needs, and crack the discipline barrier, construct school place, school enterprise, and school community. It is also necessary to promote the reform of engineering education and teaching, establish the training path of innovative engineering talents, form the training mode of innovation and entrepreneurship ability of emerging engineering talents based on innovative engineering education concept, establish the emerging concept, emerging mode, emerging structure, emerging system and emerging quality of engineering education, and play a supporting role for regional economic development and industrial upgrading [7]. How to effectively evaluate the effect of the emerging engineering talent training model, form a closed loop of quality engineering, and constantly improve the training quality of emerging engineering talents is an urgent problem to be solved in higher engineering colleges [8]. Taking the development of emerging engineering research and practice of the university as an opportunity, and the innovation and entrepreneurship talent training mode as a carrier, the effect evaluation system of the training mode of emerging engineering students in local universities is constructed to highlight the new quality, new standard and new system, improve the talent training mode, and enhance the quality of talent training and employability [9].

2. Design of index system

The evaluation system of supporting conditions for innovation and entrepreneurship education for college students can refer to the guiding standards for the recognition of demonstration universities for deepening innovation and entrepreneurship education reform, which highlights the achievements of the construction, and focuses on the reform of key areas and key links such as curriculum system, training mechanism, innovation of teaching methods, practical training, and faculty. It is necessary to continue to promote the construction of high-quality online open courses for innovation and entrepreneurship education, the construction of featured demonstration courses for "integration of innovation and entrepreneurship", carry out teacher training, participate in the China International "Internet +" College Students Innovation and Entrepreneurship Competition, and evaluate the activities of "Red Dream Building Tour for Young People". Additionally, there are 3 first-level indicators of organizational guarantee, educational process, educational effect and characteristic demonstration for the design evaluation organization, 12 second-level indicators, including development planning, working mechanism, system construction, and fund guarantee indicators. The education process includes 5 second-level indicators, such as training program design and implementation, curriculum construction, teaching innovation, teacher team and practical training. Educational effect and characteristic demonstration cover 3 second-level indicators and 37 third-level indicators, such as educational effect, social benefit and characteristic project. The first-level indicator education process, the second-level indicator practical training, and the third-level indicator jointly
build a batch of off-campus innovation and entrepreneurship practice platforms (including entrepreneurship training or entrepreneurship practice base, entrepreneurship incubation base, etc.) with industry enterprises and scientific research institutes to evaluate the support conditions of college students’ innovation and entrepreneurship education [10].

3. Establish evaluation models

From the above evaluation indicator system of innovation and entrepreneurship education conditions, it can be seen that there are many supporting factors that affect innovation and entrepreneurship education, and it is very complex. Most of the factors have the problems of inaccurate qualitative evaluation, quantitative evaluation and incomplete evaluation. At the same time, due to the different perspective of experts and different experiences, it is inevitable that there are subjective and blindness in the process of review. According to the theory of fuzzy mathematics and the method of fuzzy hierarchical analysis, a quantitative fuzzy mathematical model is established to evaluate the condition support system of innovation and entrepreneurship education for emerging engineering talents.

3.1. Basic principles of Fuzzy Analytic Hierarchy Process (FAHP)

Fuzzy mathematics is a mathematical subject dealing with fuzzy phenomena, and has become an important mathematical theory and method in modern information science. At the same time, it has also formed a distinctive fuzzy application technology. In nearly 50 years of development, fuzzy mathematics has developed rapidly, and its research achievements involve artificial intelligence, fuzzy control, fuzzy reasoning, fuzzy recognition and other fields. Fuzzy mathematics theory and application methods are being accepted by more and more natural and social science workers, and have achieved remarkable success in many fields, such as natural science, social science, engineering technology, industrial process control, information science, artificial intelligence, meteorology, environmental protection, behavioral science, management science, military science, aerospace technology, prediction and decision-making technology.

Fuzzy theory is developed on the basis of fuzzy set theory. After more than half a century of development and application, it mainly includes fuzzy set theory, fuzzy logic, fuzzy reasoning and fuzzy control. The most effective and widely used field is fuzzy control, which can solve unexpected or difficult problems that can not be solved by traditional control theory in various fields, and has achieved some convincing results. With the help of scientific method theory and the application operation of mathematics and matrix, it can avoid subjective, biased and empirical setting methods as far as possible, distribute all kinds of weights reasonably, and ensure the objective and true evaluation. The Analytic Hierarchy Process (AHP) and its improved Fuzzy Analytic Hierarchy Process (FAHP) are suitable for the situation where the main decision is judged qualitatively and the final result is difficult to be measured accurately. After deeply analyzing the essence, related factors and internal correlation of the difficult quantitative decision problem, the corresponding hierarchical model structure is constructed, and then less quantitative information is used.

3.2. Mathematical model of Fuzzy Analytic Hierarchy Process (FAHP)

Analytic Hierarchy Process (AHP) is a practical multi-criteria evaluation method proposed by T.L.Saaty, an American operations researcher and professor at the University of Pittsburgh in the mid-1970s. The key link of AHP is to establish the judgment matrix, however, through analysis, it is found that the consistency index of judgment matrix is difficult to reach, and the consistency of judgment matrix is different from that of human decision thinking. In addition, the 1-9 scale method is difficult to achieve the consistency of judgment. Based on the above reasons, fuzzy consistency matrix is introduced into hierarchical analysis, and the weight of evaluation index is determined by establishing fuzzy consistency matrix, which is called Fuzzy Analytic Hierarchy Process (FAHP).
3.2.1. Build a hierarchical structure. Through the analysis of the evaluation factors, the evaluation model is established, as shown in Table 1.

**Table 1.** Hierarchical structure

| Target layer | Criteria layer | Indicator layer |
|--------------|----------------|-----------------|
| A1           | B1             | C1              |
|              |                | C2              |
|              |                | C3              |
|              |                | C4              |
|              | B2             | C5              |
|              |                | C6              |
|              |                | C7              |
|              |                | C8              |

3.2.2. Build complementary judgment matrix. Fuzzy complementary judgment matrix is a pairwise comparison of the importance between this level and related indicators for a certain index in the previous layer. It is usually denoted by \( R=(r_{ij})_{n \times n} \). Assuming that the index \( C \) in the upper level is related to the index in the next level, therefore, the fuzzy consistent judgment matrix can be expressed as:

\[
\begin{bmatrix}
    c & a_1 & a_2 & \cdots & a_n \\
    a_1 & r_{11} & r_{12} & \cdots & r_{1n} \\
    a_2 & r_{21} & r_{22} & \cdots & r_{2n} \\
    \vdots & \vdots & \vdots & \ddots & \vdots \\
    a_n & r_{n1} & r_{n2} & \cdots & r_{nn}
\end{bmatrix}
\]

Among them, \( r_{ij} \) reflects that when the index \( a_i \) and \( a_j \) are compared with the index \( C \) at the previous level, \( a_i \) and \( a_j \) have a fuzzy relationship "... is much more important than... ". In order to determine the membership degree, a fuzzy judgment scale of 0.1-0.9 should be established, as shown in Table 2. The fuzzy judgment matrix can be obtained as follows:

\[
R = \begin{bmatrix}
    r_{11} & r_{12} & \cdots & r_{1n} \\
    r_{21} & r_{22} & \cdots & r_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{n1} & r_{n2} & \cdots & r_{nn}
\end{bmatrix}
\]

**Table 2.** Criteria scale of 0.1 - 0.9

| Scale | Definition                                 | Note                                                   |
|-------|-------------------------------------------|-------------|
| 0.5   | Equally important                         | The two elements are equally important                 |
| 0.6   | Slightly important                        | One element is slightly more important than the other   |
| 0.7   | Obviously important                       | One element is obviously more important than the other  |
| 0.8   | Much more important                       | One element is much more important than the other       |
| 0.9   | Extremely important                       | One element is extremely important than the other       |
| 0.1, 0.2, 0.3, 0.4 | Reverse comparison                   | If the judgment \( r_{ij} \) is obtained by comparing the element \( a_i \) with the element \( a_j \), then the judgment \( r_{ij} \) is obtained by comparing the element \( a_i \) with the element \( a_j \) as \( r_{ij}=1-r_{ji} \) |

The fuzzy complementary matrix \( R \) has the following properties:

\[
r_{ij} = 0.5, i = 1,2, \cdots n; \\
r_{ij} = 1 - r_{ji}, i = 1,2, \cdots n; j = 1,2, \cdots n;
\]
3.2.3. The weight is calculated by fuzzy consistent matrix. When constructing fuzzy judgment matrix, the consistency of fuzzy judgment matrix should be considered. However, in the actual decision analysis, the consistent judgment matrix cannot be constructed directly. Therefore, the following formula needs to be transformed, thus obtaining the fuzzy consistency matrix.

$$r_{ij} = \frac{r_i - r_j}{2(n-1)} + 0.5$$  \hspace{1cm} (1)

Among them,

$$r_i = \sum_{k=1}^{n} a_{ik}, i = 1, 2, \cdots n$$

According to the following formula, the relative weight $w_i$ of each index in the matrix can be obtained:

$$w_i = \frac{1}{n} - \frac{i}{2a} + \frac{1}{na} \sum_{k=1}^{n} r_{ik}, i = 1, 2, \cdots n$$ \hspace{1cm} (2)

The parameter $a \geq (n-1)/2$, so as to ensure that the ranking weight $w_i \geq 0$, the smaller the value of $A$ indicates that the decision maker attaches more importance to the difference of the importance of factors. In practical application, $a = (n-1)/2$.

3.2.4. Calculation results. According to the opinions of relevant experts, a quantitative scale of 0.1-0.9 is adopted to construct the fuzzy judgment matrix of the criterion layer relative to the target layer, as shown below:

$$R = \begin{pmatrix} 0.5 & 0.6 \\ 0.4 & 0.5 \end{pmatrix}$$

Similarly, the fuzzy judgment matrix of index layer for criterion layer and index layer for criterion layer can be obtained as follows.

$$R_1 = \begin{pmatrix} 0.5 & 0.4 & 0.9 & 0.8 \\ 0.6 & 0.5 & 0.9 & 0.9 \\ 0.1 & 0.1 & 0.5 & 0.6 \\ 0.2 & 0.1 & 0.4 & 0.5 \end{pmatrix}$$

$$R_2 = \begin{pmatrix} 0.6 & 0.5 & 0.9 & 0.5 \\ 0.8 & 0.7 & 0.5 & 0.9 \\ 0.4 & 0.5 & 0.4 & 0.5 \end{pmatrix}$$

The fuzzy consensus judgment matrix is obtained after adjustment, and the weight result is obtained by calculating the fuzzy consensus judgment matrix. Take the first-level index as an example, input the matrix in the excel, use the SUM( )function to calculate the row sum, and then use formula 1 to get the fuzzy consistency matrix. Since it is a second-order matrix, so $n=2$, then $a=0.5$. Thus, combining with formula 2, the weight result can be obtained.

3.3. Evaluation model of Fuzzy Analytic Hierarchy Process (FAHP)

3.3.1. Determine the evaluation index set. The first-level index set for the evaluation of the conditions of innovation and entrepreneurship education for college students under the background of emerging engineering is denoted as $Q$ ($Q_i = \{q_1, q_2, q_3, ..., q_k\}$, and is divided into an evaluation sub-index, such as the evaluation of the conditions of innovation and entrepreneurship education = \{organizational guarantee, education process, education effect and characteristic demonstration\}. The second-level indicator set for determining the evaluation indicators affecting $i$ ($i=1, 2, ..., k$) is recorded as $Q_i$ ($Q_i = \{q_{i1}, q_{i2}, q_{i3}, ..., q_{ikm}\}$), indicating that the $i$th evaluation indicator set has $1$ sub-evaluation index. For example, the educational process = \{training scheme design and implementation, curriculum construction, teaching innovation, teaching staff, practical training\}. The third-level indicator set for determining the evaluations of ($j=1, 2, ..., 1$) that affects the $i$ evaluation indicators is recorded as $Q_{ij}$ ($Q_{ij} = \{q_{ij1}, q_{ij2}, q_{ij3}, ..., q_{ijkn}\}$), indicating that the $j$th
sub-evaluation index of the ith evaluation has m basic evaluation indexes. For example, practical training = {indicators and industry enterprises, off-campus innovation and entrepreneurship practice platforms jointly built by research institutes and other institutions (including entrepreneurial training or entrepreneurial practice base, entrepreneurial incubator base, etc.)}.

3.3.2. Determine index weights and evaluation sets. The above mathematical model of index weight is based on the quantitative scale of 0.1-0.9 used by experts to make judgment on each evaluation index and give the weight. The weight sets of evaluation indexes at all levels are obtained through calculation. The evaluation set evaluates the evaluation target according to its merits and demerits. It is assumed that there are n levels, denoted as $P = \{p_1, p_2, p_3,..., p_n\}$. Comment sets are defined as $P = \{\text{excellent, good, average, poor, very poor}\}$.

3.3.3. Establish a single factor evaluation matrix. Single factor fuzzy evaluation is to evaluate from a single factor to determine the degree of membership of the evaluation object to the elements of the evaluation set. The membership matrix (single factor matrix) composed of the membership degree of each evaluation index in $Q_{ij}$ is:

$$R_{ij} = \begin{bmatrix}
R_{ij1} & r_{ij12} & \cdots & r_{ij1n} \\
R_{ij2} & r_{ij22} & \cdots & r_{ij2n} \\
\vdots & \vdots & \ddots & \vdots \\
R_{ijn} & r_{ijm2} & \cdots & r_{ijmn}
\end{bmatrix}$$

$r_{ijgh}$ is membership function, representing the membership degree of the gth $(g=1, 2, ..., m)$ basic evaluation index of the jth sub-evaluation index of the ith evaluation index in $Q_{ij}$ for the evaluation grade $p_h$ $(h = 1, 2, ..., n)$. It can be calculated by the following formula:

$$r_{ijgh} = \frac{C_h}{\sum_{h=1}^{n} C_h}$$

In the formula, $C_h$ is the g basic evaluation index $q_{ijg}$ of the j sub-evaluation index of the i evaluation index, which is evaluated as the hth result $p_h$ $(h = 1, 2, ..., n)$.

3.3.4. Establish a fuzzy comprehensive evaluation model

(1) First-level fuzzy comprehensive evaluation

According to the above $R_{ij}$ relational matrix, the fuzzy comprehensive evaluation result of the jth sub-evaluation index of the ith evaluation index in $Q_{ij}$ is:

$$C_{ij} = D_{ij} \cdot R_{ij} = x_{ij1}, x_{ij2}, ..., x_{ijm} \begin{bmatrix} R_{ij1} \\ R_{ij2} \\ \vdots \\ R_{ijn} \end{bmatrix} = C_{ij1}, C_{ij2}, ..., C_{ijn}$$

$$C_{ijh} = \sum_{g=1}^{m} x_{ijg} \cdot r_{ijgh} (h = 1, 2, ..., n)$$

(2) Second-level fuzzy comprehensive evaluation

The fuzzy evaluation matrix of the evaluation index can be obtained from the above equation:

$$R_i = \begin{bmatrix}
C_{i1} \\
C_{i2} \\
\vdots \\
C_{il}
\end{bmatrix} \begin{bmatrix}
c_{i11} & c_{i12} & \cdots & c_{i1n} \\
c_{i21} & c_{i22} & \cdots & c_{i2n} \\
\vdots & \vdots & \ddots & \vdots \\
c_{il1} & c_{il2} & \cdots & c_{iln}
\end{bmatrix}$$

$C_{ijh}$ represents the membership degree of the jth $(j = 1, 2, ..., l)$ evaluation index of the ith evaluation index for the evaluation grade $p_h$ $(h = 1, 2, ..., n)$.

According to the original model of fuzzy evaluation, the second-level comprehensive evaluation is carried out, and the evaluation results of each evaluation index can be obtained as follows.
$$B_i = D_i \cdot R_i = x_{i1}, x_{i2}, \ldots, x_{il} = \begin{bmatrix} C_{i1} \\ C_{i2} \\ \vdots \\ C_{il} \end{bmatrix} = b_{i1}, b_{i2}, \ldots, b_{in}$$

$$b_{ih} = \sum_{j=1}^{l} x_{ij} \cdot r_{ijh} (h = 1, 2, \ldots, n)$$

It represents the membership degree of the ith evaluation index related to the evaluation grade ph (h = 1, 2, \ldots, n).

(3) Third-level fuzzy comprehensive evaluation

The fuzzy matrix of the evaluation indicators is:

$$R = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_k \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \ldots & b_{1n} \\ b_{21} & b_{22} & \ldots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{k1} & b_{k2} & \ldots & b_{kn} \end{bmatrix}$$

According to the original model of fuzzy evaluation, the third-level synthesis can be obtained under the background of emerging engineering students innovation and entrepreneurship education conditions support evaluation results:

$$A = D \cdot R = x_1, x_2, \ldots, x_k = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_k \end{bmatrix} = a_1, a_2, \ldots, a_k$$

$$a_{ih} = \sum_{i=1}^{k} x_i \cdot r_{ih} (h = 1, 2, \ldots, n)$$

It represents the membership degree of college students' innovation and entrepreneurship education conditions support evaluation level ph (h = 1, 2, \ldots, n).

(4) Results calculation and evaluation

The maximum membership principle is used to determine the evaluation results. According to the F value, the evaluation can be divided into five levels, as shown in Table 3.

| F value     | [0, 60) | [60, 70) | [0, 60) | [70, 80) | [90, 100) |
|-------------|---------|---------|---------|---------|---------|
| Comment set | Very poor | Poor | General | Good | Excellent |

4. Results and discussion

From the calculation and evaluation of the above results, it can be seen that there are many and complex factors affecting innovation and entrepreneurship. Many influencing factors are uncertain or unstable, and most indexes are fuzzy. At the same time, experts often judge indicators with subjectivity or fuzzy reasoning. Therefore, according to the fuzzy mathematics theory and the fuzzy analytic hierarchy process, the fuzzy mathematical model of quantitative evaluation is established to evaluate innovation and entrepreneurship education in engineering colleges and universities. The model can be integrated at three levels, and the evaluation results and evaluation grades can be supported by the conditions of innovation and entrepreneurship education for college students under the background of emerging engineering. Therefore, it can realize the quantitative, diversified, process, efficient, flexible and quality evaluation of innovative entrepreneurship education for college students.

Acknowledgment

This work was supported by:
1) Second National New Engineering Research and Practice Projects: The Exploration and Practice of Cultivating the Ability of Innovation and Entrepreneurship of Industrial Talents under the New Engineering Background (E-CXCYYR20200921)
2) Higher Education Reform Project in Heilongjiang Province: Exploration and Practice of College Students' Innovation and Entrepreneurship Education and its Integration Progressive Support System under the New Engineering Background.

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