A New Mathematical Method of Evaluation on Vietnam's Higher Education System Reveals the Need of Improving Accessibility and Research Based on Experimental Analysis

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***Abstract*-This paper designs a mathematical evaluation model based on analytical hierarchy process (AHP) to assess higher education systems of countries worldwide. After applying the model to higher education systems of China, the USA, and Vietnam, the article quantifies and compares the education indicators of the three countries. By analyzing Vietnam's historical education data based on principle component analysis (PCA), the article identifies the most remarkable aspects for improvement. The paper also provides a prediction model on Vietnam's higher education system and makes a forecast. Based on this prediction and previous evaluation results, the article proposes a series of education development actions for Vietnam.**

Keywords: Higher education evaluation, Quantification, Analytic hierarchy process, Principal component analysis, Linear regression

I. Evaluation Model for the Health of Higher Education System

A. Selection of Indicators

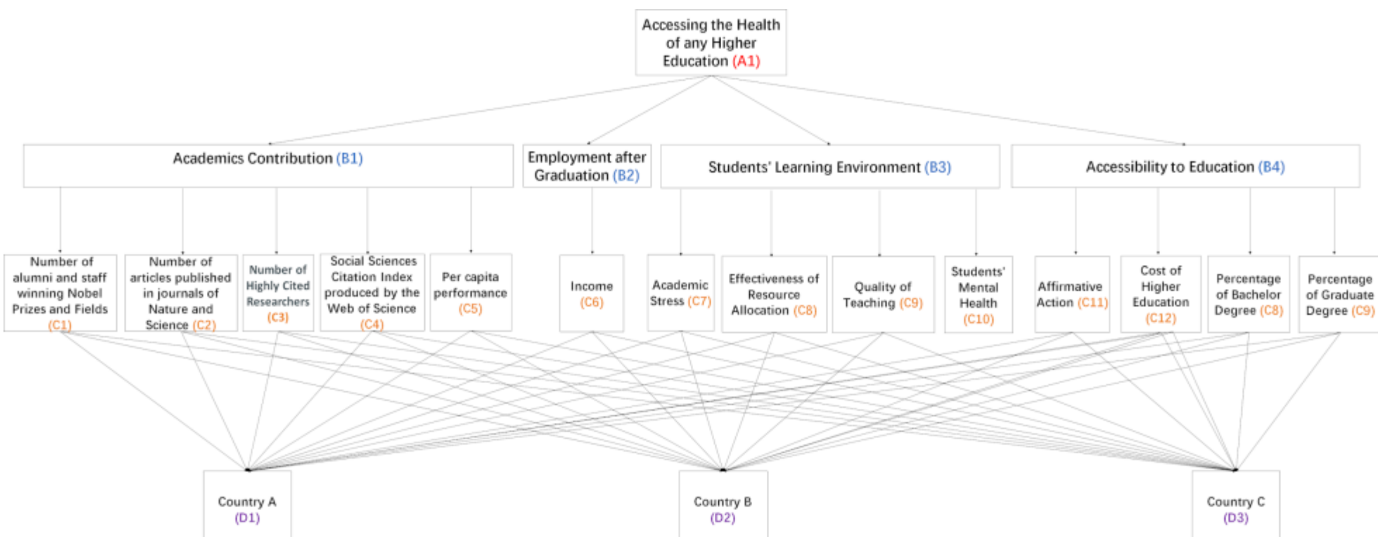

Figure 1 model indicators

To establish an evaluation system for a country's higher education system, we design an evaluation system (see the figure above) composed of various indexes to measure the health of any countries' education system from various perspectives. In general, the evaluation index system should abide by the following principles: systematicness, scientificity, comparability, measurability (i.e. observability) and independence. Therefore, we chose 4 general independent indexes: academic contribution (B1), employment after graduation (B2), students' learning environment (B3), and accessibility to education (B4)-as components of the first factor layer. By refining these general factors, we found multiple indexes to quantify these factors so that our evaluation system is comprehensive, measurable, and systematic.

B. Determination of Weight for Each Index by AHP

To determine the weights of each factor, we apply the Analytic Hierarchy Process(AHP). This method helps us to convert the factors to measurable weights of the evaluation system. We firstly build a 4×4 comparison matrix to address the importance of the 4 general factors (B1 to B4) to the target layer-assessing the health of any education (A1). To make comparison between two factors, we use a scale of importance, which is shown below:

Table 1 Scale of importance

Scale	1	3	5	7	9
Implication	Equally Important	Slightly More Important Than	Obvious More Important Than	Strongly More Important Than	Thoroughly More Important Than

Note that 2,4,6,8 is the median value of the two adjacent judgments shown above.

According to this scale, we obtain the following comparison matrix:

$$
\begin{array}{c c}
 & \begin{array}{cccc} \mathbf{B1} & \mathbf{B2} & \mathbf{B3} & \mathbf{B4} \end{array} \\
\begin{array}{c} \mathbf{B1} \\ \mathbf{B2} \\ \mathbf{B3} \\ \mathbf{B4} \end{array} & \begin{bmatrix} 1 & 4 & 0.33 & 4 \\ 0.25 & 1 & 0.2 & 1 \\ 3 & 5 & 1 & 5 \\ 0.25 & 1 & 0.2 & 1 \end{bmatrix}
\end{array}
$$

In general, we consider B4 as the most important matrix, since, as mentioned before, public participation is the foundation of an education system. B1 is slightly less important than B4, but it is also significant since an education system needs to have effective output to human society, which is scientific contributions. Lastly, B2, B3 are less important than B1, but they also serve as important factors to be included.

After testing on the consistency of this matrix, we obtain that λmax=4.0973. According to the Random Consistency Index Chart, we have RI=0.9 when n=4. Calculating the consistency index (CI) using the formula CI=(λmax-n)÷(n-1), we have CI=0.03 < RI/10=0.09, so this comparison matrix passes the consistency test. Lastly, by calculating and normalizing the eigenvector, we obtain the weights for each factor, which is shown below:

Table 2 The weights for each factor

Factors	B1	B2	B3	B4
Weight	28.6%	8.8%	53.6%	8.8%

After determining weights of the B-layer to A1, the same method is used to calculate of weight, we summarize the percentages of each factor and sub-factors, as shown in the figure below:

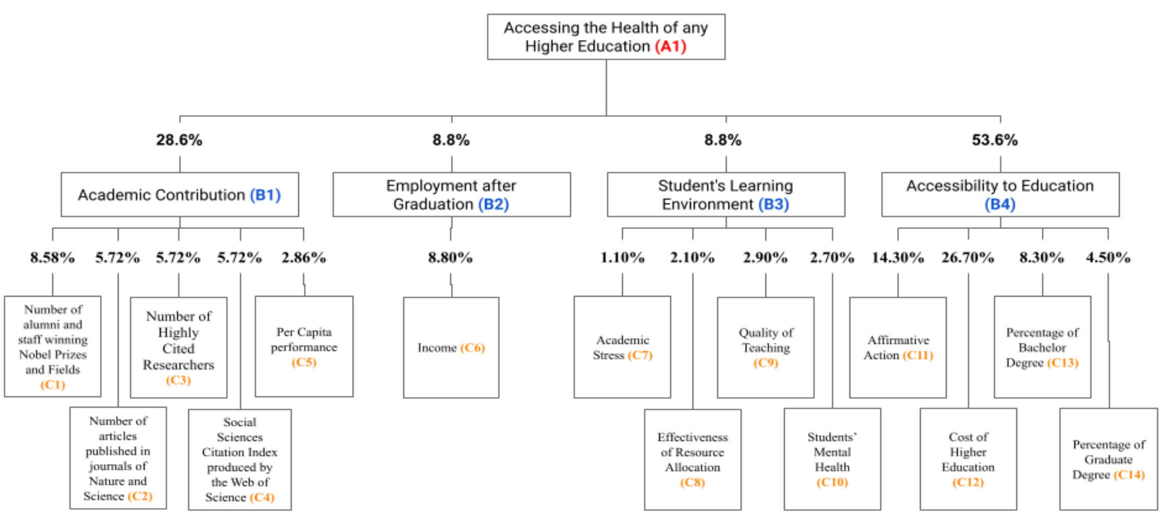

Figure 2 Evaluation system

C. Quantification of Each Indicator

C1: Number of Nobel Prize and Fields Medal Winners [1]

$$S_1 = \frac{N}{59} \times 85.7 + \frac{F}{7} \times 14.3 \qquad (1)$$

Here, the weights of Nobel prizes and Fields medals has a ratio of 1 to 6 since Nobel prizes include 6 subject areas while Fields medals only refer to mathematics.

C2: Number of Articles Published in Nature and Science [2]

$$S_2 = \frac{P}{1158} \times 100 \quad (2)$$

C3: Number of highly cited researchers [3]

$$S_3 = \frac{N_h}{2650} \times 100 \quad (3)$$

C4: Articles published in the Social Science $S_4 = \frac{N_s}{7250} \times 100$ (4)

C5: Per Capita Performance (weighted) [3]

$$S_5 = \frac{P_{av}}{R} = (N_s + P + N_h + 100N + 250F)/R \times 8170.83 \quad (5)$$

C6: Employment of Graduation [4]

$$S_6 = \frac{(S_g - A_s)}{13000} \times 100 \quad (6)$$

C7: Academic Stress

$$S_7 = min\,(\frac{A_z}{8} \times 100, 100) \quad (7)$$

It is assumed that students' sleep time is completely influenced by academic pressure. The more intense the academic pressure is, the fewer students sleep. According to recognized health theories, an ideal sleep period is 8 hours long, and thus we take a country's college students' average sleep time of 8 hours as the full score, and if that exceeds 8 hours, it is still 100 points.

C8 &C9: Education Resources

The allocation of educational resources greatly measures the learning quality of college students. Here, C8 and C9 measure educational resource allocation from two degrees: material resources and faculty resources. According to the National Center for Educational Statistics, "a good student-to-faculty ratio would meet or exceed the national average of 18 students per faculty member." Based on this estimation, we set the full-score student-faculty ratio as 1:15 [15], and the following formula is applied:

$$S_8 = \{\frac{1500T_t}{T_s}\,(T_t/T_s \leq \frac{1}{15})\ 100, (T_t/T_s \geq \frac{1}{15}) \quad (8)$$

For C9, we simply combined qualitative judgment and quantification:

$$J_i = \{1(the\ country\ has\ such\ abundant\ resource)\ 0(the\ country\ is\ lack\ of\ such\ resource)$$

$$S_9 = \sum_{i=1}^{2} 50 \times J_i \quad (9)$$

C10: Students' Mental Health

$$S_{10} = 100 - \frac{S_p}{100} \quad (10)$$

C11: Affirmative Action

K1 stands for racial quota, K2 for gender quota, K3 for disabled accommodation, and K4 for LGBTQ Accommodation, each weighing 25 points.

$$K_i = \{1(the\ country\ has\ applied\ related\ affirmative\ policies)\ 0(few\ or\ no\ policies\ have\ every\ been\ made) \quad S_{11} = \sum_{i=1}^{4} 25 \times K_i \quad (11)$$

C12: Cost of Education

We set its tuition fee 61850 $ as the 0 standard, and obtained the following formula:

$$S_{12} = \frac{(61850 - C_e)}{61850} \times 100 \quad (12)$$

C13: Percentage of Bachelor Degree[6]

Based on a database provided by OECD, Russia has the highest percentage of bachelor $degree-54%. So we set 54% as the full score standard for this indicator.

$$S_{13} = \frac{Pc}{54\%} \times 100 \quad (13)$$

C14: Percentage of Master Degree and Above [6]

According to OECD, Luxembourg has the highest percentage of master degrees and above-33%. So we set 33% as the full score standard for this indicator. The score is calculated as below:

$$S_{14} = \frac{Pm}{33\%} \times 100 \quad (14)$$

G: Health Index of a Higher Education System

$$G = W_1S_1 + W_2S_2 + W_3S_3 + \ldots + W_{14}S_{14} \quad (15)$$

Where W_1 , W_2 ,..., W_{14} are the weights for each index.

II. Application of Our Evaluation Model

Table 3 The analysis result of USA, China and Vietnam

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	G
US	100	100	100	100	100	27.2	83.8	100	83.3	89.0	100	64.3	36.1	35.5	74.8
CH	4.4	19.5	29.0	29.1	8.9	50.4	87.5	100	93.8	92.5	75	99.0	14.2	16.8	56.5
VT	0	1.5	0.1	0.3	13.3	89.5	68.8	50.0	100	94.9	50	99.7	4.3	1.0	51.6

We used our evaluation model to assess the higher education systems of the USA, China, and Vietnam. These three countries have strong representativeness: the USA being the representative of developed countries, China being the representative of top developing countries, and Vietnam being the representative of bottom developing countries.

It is evident from the data that Vietnam is struggling with every factor in academic contribution compared with China and the US. It is doing the best in the cost of education, but the worst in affirmative action since it has no accommodation policies for the disabled and the LGBTQ group and the percentages of undergraduates and graduate students. Vietnam's student stress level is not too high, and it seems like they also have better mental health than their counterparts while also having an excellent student-to-teacher ratio. However, Vietnam has split the accessibility of education. The only part lacking is the necessary facilities for students in and out of class. Income for Vietnam students needs to be improved too as both countries outclass it.

For Vietnam to improve the higher education system, it needs to regard China as its goal for the next few years. They should consider fixing their affirmative action system as this will positively impact the percentage of undergraduates. At the same time, investments in building school infrastructure will also improve its students' learning atmosphere. In the long term, these should positively impact the academic contribution and the student income as the student qualities improve, which will serve to be a smooth transition to the US's educational system in the distant future.

III. Analysis on Vietnam's Higher Education System by PCA

A. PCA on Vietnam's historical data

We process the data by using the formula $\underline{x} - x$ (decentralization), and then, using SPSS, we get the correlation matrix of pre-processed variables. It can be concluded that the absolute values of the correlation coefficients between the 11 indicators are mostly close to 1; that is to say, the correlation between them is relatively strong, so the 11 chosen indicators are suitable for Principal Component Analysis.

According to the correlation results, principal component analysis is carried out by using MATLAB software. The results are shown below:

Total Variance Explained

	Inital Eigenvalue			The Sum of Squared Loading		
Composition	Total	% Variance	Total %	Total	% Variance	Total %
1	6.648	60.439	60.439	6.648	60.439	60.439
2	1.986	18.051	78.490	1.986	18.051	78.490
3	1.469	13.353	91.843	1.469	13.353	91.843
4	.409	3.723	95.565			
5	.306	2.785	98.350			
6	.110	1.000	99.350			
7	.063	.572	99.921			
8	.006	.051	99.972			
9	.003	.028	100.000			
10	2.081E-16	1.892E-15	100.000			
11	-5.380E-16	-4.891E-15	100.000			

Extraction method: principal component analysis method.

Figure 3 Results of PCA

It can be seen from the table that the cumulative variance contribution of the first three principal components has reached 91.843%, indicating that the first three principal components basically contain all the information of all the variables. Combined with the result of the scree plot, we take the first three principal components into consideration. According to the corresponding eigenvectors describing the linear relation between the variables and principal components, we can express the linear correlation between the principal components and variables as the following:

$$x_1 = -0.535P + 0.861N_s + 0.563N_h + 0.839P_{av} + 0.974S_g - 0.022T_t - 0.333S_p + 0.986C_e + 0.923P_c + 0.987P_m + 0.891RI$$

$$x_2 = 0.474P + 0.311N_s - 0.112N_h + 0.367P_{av} + 0.199S_g + 0.794T_t + 0.823S_p + 0.049C_e + 0.017P_c + 0.126P_m - 0.389RI$$

$$x_3 = -0.610P - 0.334N_s + 0.707N_h - 0.314P_{av} - 0.167S_g + 0.534T_t + 0.248S_p - 0.006C_e + 0.105P_c - 0.023P_m + 0.013RI$$

According to the factor scoring function established on the rotated component matrix:

$$F_j = a_{j1}x_1 + a_{j2}x_2 + \ldots + a_{jp}x_p, j = 1,2\ldots,m \quad (16)$$

substituting it into the original data, after standardization, we obtain the scores of the three principal factors: F_1=64.764, F_2=20.335 F_3=14.901. It can be seen that the score of main factor X1 is higher than that of main factors X2 and X3, which indicates that the influence of main factor X1 on the health index of Vietnam's higher education system is stronger than that of the main factors X2 and X3. According to the sum of the product of the percentage of information contained in the three principal factors (F1, F2, and F3) and the load of each factor after rotation, the score of the each evaluation index is obtained as below:

Table 4 The score of the top 11 evaluation indices

Rank	1	2	3	4	5	6	7	8	9	10	11
Variable	Pm	Ce	Sg	Pc	Pav	Ns	RI	Nh	P	Tt	Sp
Score	66.14	64.94	62.8	61.6	57.12	57.11	49.98	44.72	34.10	22.68	3.14

B. *Conclusion on Selection of Indicators*

According to this scoring chart, we select the six most influential indicators-Pm, Ce, Sg, Pc, Pav, Ns-and take them as the key indicators to be improved. These indicators, along with N, F, and Ac that we have already chosen, correspond to the following aspects: C1, C2, C5, C8, C11, C12, C13 and C14.

IV. Prediction and policy making

A. *Linear Regression Prediction Model*

We try to estimate the future trend of healthy index (G) that fluctuates randomly and increases with time. Let *Gn* denote the health index of Vietnam's higher education in the nth year AD. Building this model by linear regression.

Let *Gn* and *n* satisfy the following linear relation:

Where *a* and *b* are both constants, and "ε" is a fluctuating random variable. Assume that the random variable is independent and identically distributed and that the average value of "ε" is 0. We also assume that the variable obeys normal distribution.

$$G_n = a + b \times n \quad (17)$$

We use the square of the vertical distance from one data point to the regression line to measure the goodness of fit, the expression is:

$$F(a,b) = \sum_{i=1}^{10} \left[G_i - (a + b \times n_i)\right]^2 \quad (18)$$

The best fitting line will be represented by the absolute minimum of the F(a,b). Let the partial derivative of F(a,b) be equal to zeros, we obtained the following equations:

$$\sum_{n=1}^{10} G_n = 10a + b\sum_{i=1}^{10} n_i$$
$$\sum_{i=1}^{10} n_i G_i = \mathrm{b}\sum_{i=1}^{10} n_i^{\,2} + \mathrm{a}\sum_{i=1}^{10} n_i \quad (19)$$

Using *Matlab*, we solved this equation and obtained the expression of our regression line:

$$G=0.8461n-1658.1 \quad (20)$$

To measure the goodness of our best-fit line, we define the quality R^2 as below:

$$R^2 = \frac{\sum_{i=1}^{10}(\hat{G}_i - \overline{G})^2}{\sum_{i=1}^{10}(G_i - \overline{G})^2} \quad (21)$$

By calculation, R2=93.1% for our best fit line. This shows that our best fit line has a high confidence level. Thus, we can conclusively say that the average growth rate of the health index of Vietnam's higher education system is 0.8461 per year. Based on this estimation, we predict that by the year 2025, 2030, and 2035, the health index will reach 55.25, 59.48, and 63.71. Moreover, by 2050, according to our model, Vietnam's higher education system will reach the level of developed countries.

We see that in recent years, Vietnam's economic growth ranks among the top in the world, and also according to Quacquarelli Symonds University ranking 2021, more and more Vietnamese universities have joined the world top 1000 ranking [7]. It can be seen that although being at the early stage of development, Vietnam's education and economy have great potential in the future. This also shows that despite being surprising, our prediction is very reasonable, considering the current development trend of Vietnam.

B. *Policy Making*

In order to solve the crucial problems in Vietnam's higher education system, we have 4 policy plans that are going to target C1, C2, C5, C8, C11, C12, C13, and C14 which we identified to be the most important issues.

Policy #1: Vietnam should consider government sponsorship for overseas study. This significantly reduces the cost of students to study abroad and can help develop Vietnam's higher education. Since China has very friendly policies for international students, and European countries such as Germany have nearly no tuition fee, Vietnam can send most students to China and Europe.

Policy #2: The Vietnamese government should incentivize companies to build around universities by giving them lands at a low cost either through lower interest rates or lower taxes. This creates a virtuous cycle between the University and the company. The University can deliver talented individuals to the firms and in return the firms can give university money through alumni donations and can serve as a geographic advantage for the university as the firms grow bigger.

Policy #3: Perhaps the most important policy is affirmative action in higher education. Vietnam has a separate education system for disabled groups and has no accommodation for LGBTQ groups. Not only should every citizen have the right to be educated, Vietnam is wasting a tremendous amount of potential by not allowing groups of individuals to be educated.

Policy #4: Since the average education level of Vietnam is relatively low, and its average tuition shows a steady trend of increase due to the increase of private universities, Vietnam needs to build more public universities to make its higher education more affordable and accessible.

However, none of these policies can smoothly run without sufficient government funding.

V. Conclusion

Strengths and Weaknesses of our Models and Proposed Policies

Strengths:

(1) We have 14 indicators which we believe are very comprehensive in terms of evaluating a country's higher education system.

(2) Each indicator is quantified, so the accuracy and measurability of the indicators are relatively high

(3) Existing evaluation systems of higher education design the weight of each indicator too randomly and too subjectively, but our model solves this problem.

(4) Our sensitivity analysis shows that our prediction model has a high goodness of fit and a good robustness.

(5) Our selection of the indicators and policies is based on PCA, which enables us to pick important aspects of Vietnam's higher education system to make policies for. This makes our policies effective and pertinent.

(6) Our policies are highly practical, since we made them based on Vietnam's basic national conditions and our prediction model.

Weaknesses:

(1) Our prediction model is not suitable for making long-term predictions, since parameters of each index will need to be adjusted change as the global economy and education develops. .

(2) Our prediction model ignores the possibility of any major disasters (natural disasters, Covid-19, economical crisis, war, etc) in the future and assumes a constant development on education.

(3) Subjectivity on each indicator's weight was inevitably involved in our Analytic Hierarchy Process.

(4) We ignore inflation's effect on income of students and that may have the wrong representation of their actual value and corresponding indicators. Also, some indicators are represented by subjective estimations by authorities, instead of statistical information. This means indicators represented by the cost of education and college students' average sleep hours may be inaccurate.

(5) Our policies require considerable government funding and. For developing countries, funds for building education may exceed the financial ability of the government.

VI. Further Applications

Our evaluation model greatly reduces the influence of subjectivity on the scoring mechanism, and it can be used for assessing higher education systems of other countries as well. After making PCA and prediction based on linear regression, we can diagnose the existing problems of a higher education system and judge whether it is on a healthy and sustainable development path. The method of determining weights of indices can also be used for other evaluation problems such as assessing national military power, technical strength, and economy.

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