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Assessing the Human Resource in Science and Technology for Asian Countries: Application of Fuzzy AHP and Fuzzy TOPSIS

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Abstract: The fuzzy analytic hierarchy process (AHP) and fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are extremely beneficial when a decision-making process is complex. The reason is that AHP and TOPSIS can prioritize multiple-choice criteria into a hierarchy by assessing the relative importance of criteria and can thus generate an overall ranking of the alternatives. This study uses fuzzy AHP and fuzzy TOPSIS to evaluate the human resource in science and technology (HRST) performance of Southeast Asian countries. The fuzzy TOPSIS analysis indicates that Singapore, South Korea, and Taiwan have similarities in their desired levels of HRST performance. That is, these three countries have better HRST performances than other Southeast Asian countries.

Keywords: TOPSIS; AHP; fuzzy theory; human resources in science and technology

1. Introduction

In the current knowledge-based economy, innovation is identified as the driver of productivity and economic growth, thereby leading to a new focus on the important role of technology, information, and learning in economic performance. For decades, science, technology, and skilled labor have been viewed as having a key role in achieving sustainable national development. Policy makers focus on the measurement of the human resource in science and technology (HRST) competitiveness. Given that Southeast Asia is the world's fastest growing region, all Southeast Asian governments consider HRST the most critical project for the future development of national competitiveness. In this context, the need to measure and analyze the most highly skilled part of the labor force is considerably important in the international level.

On the basis of the shortcomings of conventional methods to measure HRST competitiveness, the main aim of the present study is to provide policy makers and practitioners with a fuzzy perspective on national HRST competitiveness evaluation and attempt to improve the accuracy and reconstruct the priority of each measurement dimension in HRST competitiveness. A total of 16 experts were invited to evaluate HRST competitiveness via the proposed fuzzy analytic hierarchy process (AHP) and fuzzy technique for order Preference by Similarity to Ideal Solution (TOPSIS) combined with multi-attribute decision-making (MADM). Fuzzy AHP was applied to determine the preference weights for the HRST competitiveness evaluation dimensions. Fuzzy TOPSIS overcomes the gaps in the alternatives between real performance values and aspired levels of each dimension and criterion to identify the best alternatives to achieve the desired HRST levels. Moreover, this study attempts to apply the revised process to assess the current HRST competitiveness status of nine Southeast Asian countries. Accordingly, the current research can provide the governments with strategic recommendations.

The remainder of this paper is structured as follows. Section 2 reviews the existing framework of HRST competitiveness. Section 3 demonstrates how fuzzy AHP and fuzzy TOPSIS are applied to real-world contexts. Section 4 applies empirical data to the adjusted HRST competitiveness model and discusses the findings. Lastly, Section 5 provides the managerial implications and conclusions.

2. Literature Review

2.1. HRST Competitiveness

The concept of competitiveness implies a win–win situation, in which one individual, firm, or country outperforms another. National competitiveness refers to a country's ability to command a substantial world market share in high-technology products while maintaining its citizens' standards of living [1]. Human resource competitiveness is the most important factor in achieving economic competitiveness [2]. High human resources competitiveness can enable enterprises achieve good performance and obtain the support of customers, shareholders, the society, and other stakeholders; and obtain the ability of long-term profit, namely, sustainable competitiveness advantage [3]. The development of HRST is a key factor in improving the competitiveness of countries [4].

Competitiveness includes efficiency and effectiveness [5]. National HRST competitiveness implies HRST of efficiency, productivity, and profitability. Efficiency indicates how to produce the maximum output while using the least amount of resource input. Productivity is the relationship between output and input. Profitability analysis measures HRST's efficiency and productivity and how profitability affects the national economic performance and peoples' earnings. Eventually, productivity must be transformed to actual economic profit to demonstrate national competitiveness.

2.2. Indicators of HRST Competitiveness

Chou, Sun, and Yen [6] selected the essential input, infrastructure, and output indicators to evaluate HRST competitiveness in accordance with the assessments of development, science, and national competitiveness.

2.2.1. Infrastructure Indicators

Pawan [7] argued that education and training are directly related to science and technology development. Sallehuddin [8] suggested that professional education plays an important role to technology development. Universities and educational institutions are responsible to training and producing scientists and technological experts, who contribute to national technology advancement. That is, the educational system creates HRST which is a key component of the national technology development.

However, possessing extensive HRST is insufficient. Values and attitudes are considerably important. Oyebisi and Agboola [9] suggested that a technical professional's attitude toward a practical system is beneficial to technological development. Undoubtedly, the impact can be extended to the societal and national levels. Madanmohan, Kumar, and Kumar [10] were convinced that a technical personnel's willingness to do and to learn is substantially more significant than the ability they possess.

Madanmohan et al. [10] explained that the expansion of technological ability is dependent on the expansion and transformation of knowledge. Without cooperation or an expansion system, the attitudes and values of HRST alone are insufficient to promote overall competitiveness. The establishment of partnerships and cooperation among universities, industry, and the government can stimulate the performance of research and development (R&D). A system of cooperation among universities, industry, and the government is extremely critical to national scientific competitiveness. The labor force can generate creativity by maximizing the various resources available. Creativity leads to knowledge that is an improvement on that of other countries.

HRST is also derived from the labor market. The evaluation of the effectiveness of labor market in improving the competitiveness of HRST requires observing the supports of group productivity for the competitive advantage of corporations and countries. Furthermore, salaries and work hours represent the rewards and benefits bestowed on HRST. According to motivation theory, such rewards identify appropriate measures that enhance employee motivation, thereby enabling enhancements in productivity and loyalty. In summary, the infrastructure indicators for evaluating competitiveness of HRST are education, values, cooperation, and the labor market.

2.2.2. Input Indicators

Geisler [11] suggested that cost items in the cost–performance model are important input indicators. A few studies have suggested that the number of R&D engineers is a key input indicator for R&D [1,10,12]. Other studies have suggested that R&D human resources and R&D budgets are key input indicators for measuring R&D performance [13,14]. Lee et al. [14] adopted four criteria, namely, R&D budget, R&D human resources, technological status, and the hydrogen technology infrastructure, to measure the national competitiveness in the hydrogen technology sector. Thus, the input indicators for evaluating competitiveness of HRST are R&D expenses and number of R&D personnel.

2.2.3. Output Indicators

Geisler [11] assessed a performance index for R&D output. The author divided immediate and intermediate outputs as two categories of the output. An immediate output index represents products that have gone through the R&D stage but have yet to reach the market (e.g. published materials, journals, patents, periodicals, new testing methods, number of doctors and the experience of scientists and engineers).

However, the intermediate output index can improve the performance index or commercialized items. This intermediate output index includes the influence on science and technology and R&D users (e.g. product improvement or the economic impact on direct users). Therefore, the output indicators for evaluating competitiveness of HRST are intermediate outputs and immediate outputs.

3. Methods

3.1. Fuzzy AHP

Fuzzy AHP is an extension of AHP [15] and is a beneficial technique for solving complicated decision problems. Any complicated problem can be deconstructed into different hierarchical levels of criteria. Within each hierarchy, a series of pair-wise comparisons are conducted to determine the importance of criteria. In AHP, experts use crisp numbers (e.g., 1, 2,$\cdots$9) to determine the importance of criteria, whereas fuzzy AHP experts use natural linguistic terms (e.g., equally important, weakly important) to express their judgments. The linguistic terms represent the corresponding fuzzy numbers defined in fuzzy membership functions [6].

3.1.1. Establishing Fuzzy Numbers

Zadeh [16] introduced the fuzzy sets, which are sets with elements that have different membership degrees. Fuzzy membership functions define the fuzzy sets on the basis of the interval of real numbers between 0 and 1. Triangular fuzzy membership functions are extensively adopted in the literature [17,18]. The reason for such an adoption is the computational simplicity of triangular fuzzy membership functions and their ability to deal with fuzzy data [19].

A fuzzy number $\widetilde{N}$ on $\mathbb{R}$ will be a triangular fuzzy number (*TFN*) if its membership function $\mu_{\widetilde{N}}(\mathrm{x}):\ \mathbb{R} \to 0,1$ is equal to Equation (1) as follows:

$$\mu_{\widetilde{N}}(\mathrm{x}) = \begin{cases} \frac{x-l}{m-l}, & l \leq x \leq m, \\ \frac{u-x}{u-m}, & m \leq x \leq u, \\ 0, & otherwies, \end{cases} \tag{1}$$

where l, m, and u are the lower, mean, and upper bounds, respectively, of the fuzzy number $\widetilde{N}$. *TFN* can be denoted by $\widetilde{N} = (l, m, u)$. The operational laws of *TFN* $\widetilde{N} = (l_1, m_1, u_1)$ and $\widetilde{N} = (l_2, m_2, u_2)$ are provided by Equations (2)–(6) (Figure 1).

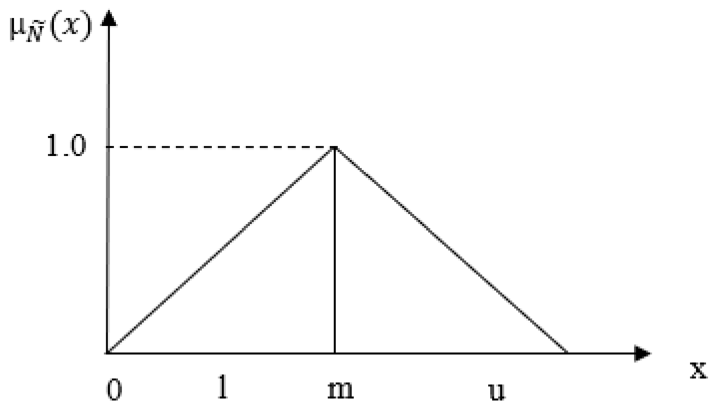

Figure 1. The membership functions of the triangular fuzzy number (TFN).

Addition of the fuzzy number $\oplus$:

$$\widetilde{N_1} \oplus \widetilde{N_2} = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2}$$

Subtraction of the fuzzy number $\ominus$:

$$\widetilde{N_1} \ominus \widetilde{N_2} = (l_1, m_1, u_1) \ominus (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \tag{3}$$

Multiplication of the fuzzy number $\otimes$:

$$\widetilde{N_1} \otimes \widetilde{N_2} = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \tag{4}$$

for $l_1, l_2 > 0, m_1, m_2 > 0, u_1, u_2 > 0$

Division of the fuzzy number $\oslash$:

$$\widetilde{N_1} \oslash \widetilde{N_2} = (l_1, m_1, u_1) \oslash (l_2, m_2, u_2) = (l_1/l_2, m_1/m_2, u_1/u_2) \tag{5}$$

for $l_1, l_2 > 0, m_1, m_2 > 0, u_1, u_2 > 0$

Reciprocal of the fuzzy number:

$$\widetilde{N}^{-1} = (l_1, m_1, u_1)^{-1} = (1/l_1, 1/m_1, 1/u_1) \tag{6}$$

for $l_1, l_2 > 0, m_1, m_2 > 0, u_1, u_2 > 0$

3.1.2. Determining the Linguistic Variables

Linguistic variables are words or sentences in a natural or artificial language. Consistent with Gumus [20], the present study uses a set of nine basic linguistic terms (see Table 1). Each membership function (scale of fuzzy numbers) is defined by three parameters for a symmetrical triangular fuzzy number (i.e., left, middle, and right points) in the range over which a function is defined.

Table 1. Linguistic terms and the corresponding TFNs.

Saaty Scale	Definition	Fuzzy Triangle Scale
1	Equally important	(1,1,1)
3	Weakly important	(2,3,4)
5	Fairly important	(4,5,6)
7	Strongly important	(6,7,8)
9	Absolutely important	(9,9,9)
2	Intermittent values between two adjacent scales	(1,2,3)
4		(3,4,5)
6		(5,6,7)
8		(7,8,9)

3.1.3. The Fuzzy AHP Method

Step 1: Conduct pair-wise comparison matrices for all criteria in the dimensions of the hierarchy system. Equation (7) shows that $\widetilde{d_{ij}^{k}}$ represents the k^{th} decision makers' preference of the i^{th} criterion over the j^{th} criterion via TFNs.

$$\widetilde{A}^k = \begin{bmatrix} \widetilde{d}_{11}^k & \widetilde{d}_{12}^k & \cdots & \widetilde{d}_{1n}^k \\ \widetilde{d}_{21}^k & \cdots & \cdots & \widetilde{d}_{2n}^k \\ \cdots & \cdots & \cdots & \cdots \\ \widetilde{d}_{n1}^k & \widetilde{d}_{n2}^k & \cdots & \widetilde{d}_{nn}^k \end{bmatrix} \tag{7}$$

Step 2: If more than one decision maker is present, then the preferences for each decision maker are average as shown in the following equation:

$$\widetilde{d_{ij}} = \frac{\sum_{k=1}^{k} \widetilde{d}_{ij}^k}{K} \tag{8}$$

Step 3: Update the pair-wise comparison matrices for all criteria in the hierarchy system dimensions on the basis of the averaged preferences.

$$\widetilde{\mathrm{A}} = \begin{bmatrix} \widetilde{d_{11}} & \cdots & \widetilde{d_{1n}} \\ \cdots & \ddots & \cdots \\ \widetilde{d_{n1}} & \cdots & \widetilde{d_{nn}} \end{bmatrix} \tag{9}$$

Step 4: Use the geometrical mean technique to define the fuzzy geometrical mean and fuzzy weights of each criterion.

$$\widetilde{\mathrm{r}}_i = \left(\prod_{j=1}^{n} \widetilde{d}_{ij} \right)^{1/n},\ i = 1, 2, \ldots, n \tag{10}$$

Step 5: Determine the fuzzy weight of the criteria.

$$\widetilde{\mathrm{w}}_i = \widetilde{\mathrm{r}}_i \otimes (\widetilde{\mathrm{r}}_1 \oplus \widetilde{\mathrm{r}}_2 \oplus \ldots \oplus \widetilde{\mathrm{r}}_n)^{-1} \tag{11}$$

Step 6: Calculate the average and normalized weight criteria.

$$\mathrm{M}_i = \frac{\widetilde{w}_1 \oplus \widetilde{w}_2 \oplus \ldots \oplus \widetilde{w}_n}{n} \tag{12}$$

$$\mathrm{N}_i = \frac{\mathrm{M}_i}{\mathrm{M}_1 \oplus \mathrm{M}_2 \oplus \ldots \oplus \mathrm{M}_n} \tag{13}$$

3.2. Fuzzy TOPSIS

TOPSIS considers an MADM problem with m alternatives as a geometric system with m points in the n-dimensional space of criteria. The proposed method is based on the concept that a chosen alternative has the shortest and farthest distances from the positive-ideal solution (i.e., achieving minimal gaps between each criterion) and the negative-ideal solution (i.e., achieving maximal levels for each criterion), respectively. TOPSIS defines an index called similarity as closest and farthest to the positive- and negative-ideal solutions, respectively. Thereafter, the proposed method chooses an alternative with maximum similarity to the positive-ideal solution [21,22]. Shadbegian and Gray [23] indicated that decision makers have difficulty assigning a precise performance rating to an alternative, the attributes of which are under consideration. The merit of using a fuzzy approach is that fuzzy numbers, instead of precise numbers, can be assigned to represent the relative importance of attributes, which is consistent with the real-world fuzzy environment. Thereafter, TOPSIS is extended to the fuzzy environment [18,24]. This method is particularly suitable for solving group decision-making problems under fuzzy environments. The fuzzy theory was briefly analyzed before the development of the fuzzy TOPSIS. Mathematical concepts were adopted from Büyüközkan, Feyzioğlu, and Nebol [25]; Kuo et al. [24]; and Wang and Chang [22].

Step 1: Determine the weights of the evaluation criteria. The present study applies fuzzy AHP to determine fuzzy preference weights.

Step 2: Construct the fuzzy decision matrix and choose the appropriate linguistic variables as alternatives for the criteria.

$$\widetilde{\mathrm{D}} = \begin{matrix} \\ A_1 \\ \ldots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & \ldots & C_n \end{matrix} \\ \begin{bmatrix} \widetilde{x}_{11} & \cdots & \widetilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \widetilde{x}_{m1} & \cdots & \widetilde{x}_{mn} \end{bmatrix} \end{matrix}, \quad i = 1,2,\ldots,m; j = 1,2,\ldots,n \tag{14}$$

$\widetilde{x}_{ij} = \frac{1}{K}(\widetilde{x}_{ij}^1 \oplus \cdots \oplus \widetilde{x}_{ij}^k \oplus \cdots \oplus \widetilde{x}_{ij}^K)$, where $\widetilde{x}_{ij}^k$ is the performance rating of the alternative A_i with respect to criterion C_j evaluated by the k^{th} expert and $\widetilde{x}_{ij}^k = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$.

Step 3: Normalize the fuzzy decision matrix. The normalized fuzzy decision matrix denoted by $\widetilde{\mathrm{R}}$ is depicted as follows:

$$\widetilde{\boldsymbol{R}} = [\widetilde{r}_{ij}]_{m \times n}, i = 1,2,\cdots,m;\ j = 1,2,\cdots,n. \tag{15}$$

Thereafter, the normalization process can be performed as follows: where $\widetilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right)$, $u_j^+ = \max_i\{u_{ij} | i = 1,2,...,n\}$. Alternatively, we can set the best aspired level u_j^+ and $j = 1,2,\ldots,n$ is equal to 1; otherwise, the worst is 0. The normalized $\widetilde{r}_{ij}$ continues to be TFNs. For trapezoidal fuzzy numbers, the normalization process can be performed in the same manner. The weighted fuzzy normalized decision matrix is stated as the following matrix $\widetilde{\mathrm{V}}$:

$$\widetilde{V} = [\widetilde{v}_{ij}]_{n \times n}, i = 1,2,\ldots,m;\ j = 1,2,\ldots,n, \tag{16}$$

where $\widetilde{v}_{ij} = \widetilde{r}_{ij} \otimes \widetilde{w}_j$.

Step 4: Determine the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS). The weighted normalized fuzzy decision matrix indicates that the elements $\widetilde{v}_{ij}$ are normalized positive TFN and their ranges belong to the closed interval [0,1]. Thereafter, we can define the FPIS A^+ (aspiration levels) and FNIS A^- (the worst levels) as follows:

$$A^+ = (\widetilde{v}_1^*, ..., \widetilde{v}_j^*, ..., \widetilde{v}_n^*) \tag{17}$$

$$A^- = (\widetilde{v}_1^-, ..., \widetilde{v}_j^-, ..., \widetilde{v}_n^-) \tag{18}$$

where $\widetilde{v}_j^* = (1,1,1) \otimes \widetilde{w}_j = (lw_j, mw_j, uw_j)$ and $\widetilde{v}_j^- = (0,0,0)$, $j = 1,2,\ldots,n$

Step 5: Calculate the distance of each alternative from FPIS and FNIS. The distances ($\widetilde{d}_i^+$ and $\widetilde{d}_i^-$) of each alternative from A^+ and A^- can be calculated using the area compensation method:

$$\widetilde{d}_i^+ = \sum_{j=1}^{n} d(\widetilde{v}_{ij}, \widetilde{v}_j^*), i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \tag{19}$$

$$\widetilde{d}_i^- = \sum_{j=1}^{n} d(\widetilde{v}_{ij}, \widetilde{v}_j^-), i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \tag{20}$$

Step 6: Obtain the closeness coefficients (relative gaps–degree) and improve the alternatives to achieve the aspiration levels in each criterion.

Opricovic and Tzeng [26] developed a compromise solution using the MCDM methods for the comparative analysis of Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) and TOPSIS. The preceding study has noted that TOPSIS cannot be used for ranking. Thus, the improved alternative chosen should have the shortest and farthest distances from the positive-ideal solution (i.e., achieving minimal gaps between each criterion) and negative-ideal solution (i.e., achieving the maximal levels in each criterion), respectively.

Therefore, we propose that $C\widetilde{C}_i$ is defined to determine the fuzzy gaps–degree on the basis of the fuzzy closeness coefficients to improve the alternatives. Once $\widetilde{d}_i^+$ and $\widetilde{d}_i^-$ of each alternative have been calculated, the similarities to the ideal solution are calculated. This step solves the similarities to an ideal solution as follows:

$$C\widetilde{C}_i = \frac{\widetilde{d}_i^-}{\widetilde{d}_i^+ + \widetilde{d}_i^-} = 1 - \frac{\widetilde{d}_i^+}{\widetilde{d}_i^+ + \widetilde{d}_i^-}, i = 1,2,\ldots,m \tag{21}$$

where we define $\frac{\widetilde{d}_i^-}{\widetilde{d}_i^+ + \widetilde{d}_i^-}$ as fuzzy satisfaction degree in the *i-th* alternative and $\frac{\widetilde{d}_i^+}{\widetilde{d}_i^+ + \widetilde{d}_i^-}$ as fuzzy gap–degree in the *i-th* alternative. We can know which and how fuzzy gaps should be improved to achieve the aspiration levels and obtain the best win-win strategy from among a fuzzy set of feasible alternatives.

4. Empirical Data Analysis and Results

After reviewing the literature, the criteria were selected to build the hierarchical systems. The present study adopts the fuzzy AHP method to evaluate the weights of the different dimensions for the HRST competitiveness of nine Southeast Asian countries, namely, Singapore, South Korea, Taiwan, Hong Kong, Malaysia, China, Thailand, the Philippines, and India. The research data and framework for the assessment of the HRST competitiveness were adopted from *The World Competitiveness Yearbook* [5]. The completion of the judgment matrix by experts is extremely important following the construction of the fuzzy AHP model.

Step 1: Obtain the weights of the evaluation dimensions.

(1) In accordance with the committee of sixteen representatives, if the relative importance of the dimensions is followed, then the pair-wise comparison matrices of the dimensions will be

obtained. We apply the fuzzy numbers provided in Table 1 and transfer the linguistic scales to the corresponding fuzzy numbers.

(2) Buckley [15] suggested computing the elements of synthetic pair-wise comparison matrix by using the geometric mean method. $\tilde{a}_{ij} = (\tilde{a}_{ij}^{1} \otimes \tilde{a}_{ij}^{2} \otimes \ldots \otimes \tilde{a}_{ij}^{11})$, for $\tilde{a}_{12}$ as the example:

$$\begin{aligned}\tilde{a}_{12} &= (1,1,1) \otimes (1/6,1/5,1/4) \otimes \cdots \otimes (5,6,7)^{1/11} \\ &= ((1 \times 1/6 \times \cdots \times 5)^{1/11}, (1 \times 1/5 \times \cdots \times 6)^{1/11}, (1 \times 1/4 \cdots \times 7)^{1/11}) \\ &= (0.387, 0.426, 0.474)\end{aligned}$$

The results can be obtained from the other matrix elements via the same computational procedure. Therefore, the synthetic pair-wise comparison matrices of the five representatives will be constructed as follows for matrix $\boldsymbol{A}$:

$$A = \begin{matrix} & D_1 & D_2 & D_3 \\ D_1 & (1.000,1.000,1.000) & (0.387,0.426,0.474) & (0.342,0.399,0.476) \\ D_2 & (2.111,2.349,2.585) & (1.000,1.000,1.000) & (0.802,0.967,1.195) \\ D_3 & (2.102,2.507,2.921) & (0.837,1.034,1.246) & (1.000,1.000,1.000) \end{matrix}.$$

(3) To calculate the fuzzy weights of dimensions, the computational procedures are displayed as the following components:

$$\begin{aligned}\tilde{r}_{D_1} &= (\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \tilde{a}_{13})^{1/3} \\ &= ((1.000 \times 0.387 \times 0.342)^{1/3},\ (1.000 \times 0.462 \times 0.399)^{1/3},\ (1.000 \times 0.474 \times 0.476)^{1/3}) \\ &= (0.510, 0.554, 0.609)\end{aligned}$$

Similarly, we can obtain the remaining $\tilde{r}_{D_i}$ as follows:

$$\begin{aligned}\tilde{r}_{D_2} &= (1.192,1.314,1.456) \\ \tilde{r}_{D_3} &= (1.207,1.374,1.538)\end{aligned}$$

The weight of each dimension can be calculated as follows:

$$\begin{aligned}\tilde{w}_{D_1} &= \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3)^{-1} \\ &= (0.510,0.554,0.609) \otimes (1/(0.609{+}1.456 + 1.538), 1/(0.554{+}1.314 + 1.374), \\ &\quad 1/(0.510{+}1.192 + 1.207)) \\ &= (0.141,0.171,0.209)\end{aligned}$$

We can also calculate the remaining $\tilde{w}_{D_i}$ as follows:

$$\begin{aligned}\tilde{w}_{D_2} &= (0.331,0.405,0.501) \\ \tilde{w}_{D_3} &= (0.335,0.424,0.529)\end{aligned}$$

(4) The COA method is used to compute the BNP value of the fuzzy weights of each dimension. As an example, the following calculation process is used to obtain the BNP value of the weight of D_1 (Infrastructure):

$$\begin{aligned}BNP_{w_{D_1}} &= [(U_{w_1} - L_{w_1}) + (M_{w_1} - L_{w_1})]/3 + L_{w_1} \\ &= [(0.209 - 0.141) + (0.171 - 0.141)]/3 + 0.141 \\ &= 0.174\end{aligned}$$

Thereafter, the weights for the remaining dimensions can be determined (see Table 2), which depicts the relative weight of the three dimensions and eight criteria obtained using the fuzzy AHP method.

Step 2: Construct the fuzzy decision matrix and choose the appropriate linguistic variables for the alternatives with respect to criteria.

The present study focuses on evaluating the human resources in the science and technology performances of Southeast Asian countries. Therefore, we assume that questionnaires have been collected and will start by building a data set from the questionnaires that are collected. The evaluators have their own ranges for the linguistic variables employed in the current study based on their subjective judgments [19]. For each evaluator with the same importance, this study employs the average value method to integrate the fuzzy/vague judgment values of the different evaluators regarding the same evaluation dimensions. The evaluators adopted linguistic terms (see Table 3), namely, "very poor," "poor," "fair," "good," and "very good," to express their opinions on the rating of companies regarding each capability criteria. The bases for such adoption are the technological data of the four companies presented in Table 4.

Using Equation (10), we can normalize the fuzzy decision matrix (see Table 5).

Step 3: Establish the weighted normalized fuzzy decision matrix.

The fourth step in the analysis is to obtain the weighted fuzzy decision matrix. Table 6 presents the resulting fuzzy weighted decision matrix.

Step 4: Determine the fuzzy positive and fuzzy negative ideal reference points.

We can define FPIS and FNIS as A^+ and A^-, respectively. This is the fifth step of the fuzzy TOPSIS analysis.

$$\begin{aligned}
&A^+ = [(1,1,1),(1,1,1),\cdots,(1,1,1),(1,1,1)] \otimes \widetilde{w}_j \\
&= [(1,1,1),(1,1,1),\cdots,(1,1,1),(1,1,1)] \otimes \\
&\ [(0.002,0.006,0.015),(0.003,0.009,0.023),\cdots,(0.025,0.048,0.089),(0.011,0.019,0.036)] \\
&= (0.002,0.006,0.015),(0.003,0.009,0.023),\cdots,(0.025,0.048,0.089),(0.011,0.019,0.036)
\end{aligned}$$

$$A^- = [(0,0,0),(0,0,0),(0,0,0),\cdots,(0,0,0),(0,0,0),(0,0,0)]$$

Step 5: Calculate the distance of each alternative from FPIS and FNIS.

The following calculation is used as an example to calculate the closeness coefficients of each of the alternatives d_1^+ and d_1^-:

$$d_1^+ = 22.074 d_1^- = 1.174$$

Step 6: Estimate the performance and rank the alternatives.

Once the distances from FPIS and FNIS are determined, the closeness coefficient can be obtained using Equation (16). The index CC_1 of the first alternative is calculated as follows:

$$C\widetilde{C}_1^- = \frac{1.174}{22.074 + 1.174} = 0.0505$$

$$C\widetilde{C}_1^+ = \frac{22.074}{22.074 + 1.174} = 0.950$$

Table 2. The weights of the dimensions and criteria by fuzzy analytic hierarchy process (AHP).

Dimensions	**Criteria**	**Sub-Criteria**	**Weights**		***BNP***	**Rank**
Infrastructure			(0.141,0.171,0.209)			
	Education		(0.144,0.207,0.299)			
		Higher education achievement	(0.115,0.169,0.245)	(0.002,0.006,0.015)	0.008	23
		Total public expenditure on education	(0.170,0.249,0.361)	(0.003,0.009,0.023)	0.012	19
		Science degrees	(0.224,0.325,0.475)	(0.005,0.012,0.030)	0.015	18
		Language skills	(0.177,0.257,0.377)	(0.004,0.009,0.024)	0.012	19
	Value		(0.187,0.280,0.418)			
		Value of society	(0.166,0.218,0.290)	(0.004,0.010,0.025)	0.013	16
		Youth interest in science	(0.266,0.349,0.461)	(0.007,0.017,0.040)	0.021	13
		Flexibility and adaptability	(0.320,0.433,0.579)	(0.008,0.021,0.051)	0.027	9
	Cooperation		(0.154,0.223,0.325)			
		Technological cooperation	(0.369,0.522,0.717)	(0.008,0.020,0.049)	0.026	10
		Knowledge Transfer	(0.166,0.224,0.310)	(0.004,0.009,0.021)	0.011	21
		Development an application of technology	(0.186,0.254,0.360)	(0.004,0.010,0.024)	0.013	16
	Labor Market		(0.192,0.290,0.433)			
		Overall productivity	(0.066,0.088,0.121)	(0.002,0.004,0.011)	0.006	
		Compensation levels	(0.225,0.315,0.468)	(0.006,0.016,0.042)	0.021	13
		Working hours	(0.410,0.597,0.838)	(0.011,0.030,0.076)	0.039	8
Input			(0.331,0.405,0.501)			
	R&D Expenses		(0.622,0.748,0.888)			
		Total expenditure on R&D per capita	(0.342,0.457,0.604)	(0.070,0.138,0.269)	0.159	3
		Business expenditure on R&D per capita	(0.410,0.543,0.725)	(0.084,0.165,0.322)	0.191	1
	Human Capital		(0.215,0.252,0.307)			
		Total R&D personnel nationwide per capita	(0.295,0.389,0.511)	(0.021,0.040,0.079)	0.046	7
		Total R&D personnel in business per capita	(0.323,0.432,0.578)	(0.023,0.044,0.089)	0.052	5
		Qualified engineers	(0.134,0.179,0.241)	(0.010,0.018,0.037)	0.022	12
Output			(0.335,0.424,0.529)			
	Intermediate output		(0.502,0.647,0.816)			
		High-tech exports	(0.439,0.567,0.721)	(0.074,0.155,0.311)	0.180	2
		Basic research	(0.343,0.433,0.558)	(0.058,0.119,0.241)	0.139	4
	Immediate output		(0.282,0.353,0.459)			
		Scientific articles	(0.437,0.604,0.816)	(0.041,0.090,0.198)	0.110	21
		Patents granted to residents	(0.190,0.253,0.346)	(0.018,0.038,0.084)	0.047	6
		Securing patents abroad	(0.109,0.143,0.195)	(0.010,0.021,0.047)	0.026	10

Table 3. Linguistic scales for the rating of each company.

Linguistic Variable	Corresponding Triangular Fuzzy Number
Very poor (VP)	(0, 1, 3)
Poor (P)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Good (G)	(5, 7, 9)
Very good (VG)	(7, 9,10)

Table 4. Subjective cognition results of evaluators towards the five levels of linguistic variables.

		A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Higher education achievement	C_1	(6.09,8.09,9.45)	(5.18,7.18,8.91)	(5.36,7.36,8.91)	(5.00,7.00,8.73)	(3.00,5.00,6.91)	(2.82,4.64,6.64)	(1.55,3.18,5.18)	(1.45,3.18,5.18)	(2.45,4.27,6.27)
Total public expenditure on education	C_2	(5.36,7.36,9.00)	(4.82,6.82,8.64)	(3.91,5.91,7.82)	(4.27,6.27,8.27)	(2.45,4.45,6.45)	(2.91,4.64,6.55)	(1.45,3.00,4.91)	(1.18,2.82,4.82)	(2.09,3.73,5.73)
Science degrees	C_3	(4.27,6.27,8.09)	(4.64,6.64,8.45)	(4.64,6.64,8.36)	(4.27,6.27,8.00)	(2.82,4.82,6.82)	(3.18,5.18,7.09)	(1.45,3.00,4.91)	(0.82,2.27,4.27)	(3.00,4.82,6.82)
Language skills	C_4	(6.27,8.27,9.64)	(2.64,4.64,6.64)	(3.18,5.18,7.09)	(5.36,7.36,9.00)	(3.73,5.73,7.55)	(2.45,4.45,6.45)	(0.91,2.45,4.45)	(2.45,4.27,6.27)	(3.91,5.91,7.82)
Value of society	C_5	(4.82,6.82,8.64)	(3.09,5.00,6.91)	(3.18,5.18,7.09)	(4.64,6.64,8.55)	(3.00,5.00,7.00)	(2.18,4.09,6.00)	(2.82,4.64,6.64)	(1.91,3.73,5.73)	(2.55,4.45,6.45)
Youth interest in science	C_6	(3.73,5.73,7.64)	(3.91,5.91,7.73)	(4.27,6.27,8.18)	(3.00,5.00,7.00)	(2.45,4.45,6.45)	(3.55,5.55,7.45)	(1.82,3.73,5.73)	(1.64,3.55,5.55)	(3.91,5.91,7.91)
Flexibility and adaptability	C_7	(4.45,6.45,8.27)	(3.55,5.55,7.45)	(5.00,7.00,8.73)	(5.36,7.36,9.09)	(2.64,4.64,6.64)	(2.90,4.80,6.70)	(2.82,4.64,6.64)	(2.55,4.45,6.45)	(3.18,5.18,7.09)
Technological cooperation	C_8	(4.82,6.82,8.55)	(4.82,6.82,8.73)	(4.27,6.27,8.09)	(4.82,6.82,8.55)	(2.45,4.45,6.45)	(2.36,4.27,6.27)	(1.36,3.18,5.18)	(1.36,3.36,5.36)	(3.00,5.00,7.00)
Knowledge transfer	C_9	(5.18,7.18,8.82)	(4.82,6.82,8.64)	(4.60,6.60,8.40)	(4.45,6.45,8.18)	(2.45,4.45,6.45)	(2.55,4.45,6.45)	(1.20,3.00,5.00)	(1.36,3.36,5.36)	(3.00,5.00,7.00)
Development an application of technology	C_{10}	(5.18,7.18,8.91)	(4.82,6.82,8.55)	(4.64,6.64,8.55)	(4.45,6.45,8.27)	(2.36,4.27,6.18)	(2.55,4.45,6.45)	(1.09,2.82,4.82)	(0.82,2.64,4.64)	(2.82,4.82,6.82)
Overall productivity	C_{11}	(5.73,7.73,9.36)	(5.55,7.55,9.27)	(5.73,7.73,9.27)	(5.73,7.73,9.27)	(3.18,5.18,7.18)	(3.55,5.55,7.27)	(1.82,3.73,5.73)	(1.64,3.55,5.55)	(3.36,5.36,7.27)
Compensation levels	C_{12}	(5.73,7.73,9.27)	(4.27,6.27,8.18)	(4.09,6.09,8.09)	(5.18,7.18,8.82)	(2.82,4.82,6.82)	(2.09,4.09,6.09)	(1.73,3.55,5.55	(1.18,3.00,5.00)	(1.91,3.73,5.73)
Working hours	C_{13}	(5.18,7.18,9.00)	(4.27,6.27,8.09)	(3.73,5.55,7.27)	(4.45,6.45,8.18)	(3.55,5.55,7.36)	(3.09,5.00,6.82)	(2.91,4.82,6.73)	(2.82,4.82,6.73)	(3.09,5.00,6.91)
Total expenditure on R&D per capita	C_{14}	(4.45,6.45,8.36)	(5.55,7.55,9.18)	(4.09,6.09,8.00)	(4.09,6.09,8.09)	(2.27,4.27,6.27)	(4.09,6.09,7.91)	(2.00,3.91,5.91)	(1.45,3.36,5.36)	(2.45,4.27,6.27)
Business expenditure on R&D per capita	C_{15}	(4.82,6.82,8.64)	(5.00,7.00,8.73)	(3.91,5.91,7.91)	(3.73,5.73,7.64)	(2.45,4.45,6.45)	(3.36,5.36,7.18)	(1.91,3.73,5.73)	(1.64,3.55,5.55)	(2.27,4.09,6.09)
Total R&D personnel nationwide per capita	C_{16}	(4.45,6.45,8.36)	(4.45,6.45,8.36)	(4.82,6.82,8.55)	(3.18,5.18,7.09)	(2.36,4.27,6.27)	(2.27,4.09,6.00)	(1.73,3.55,5.55)	(1.45,3.36,5.36)	(2.27,3.91,5.91)
Total R&D personnel in business per capita	C_{17}	(5.18,7.18,8.82)	(4.64,6.64,8.36)	(4.09,6.09,7.91)	(4.09,6.09,7.91)	(2.36,4.27,6.27)	(2.45,4.27,6.27)	(1.91,3.73,5.73)	(1.64,3.55,5.55)	(2.36,4.09,6.00)
Qualified engineers	C_{18}	(6.27,8.27,9.45)	(5.73,7.73,9.00)	(5.36,7.36,8.73)	(6.27,8.27,9.45)	(3.91,5.91,7.55)	(3.18,5.18,7.00)	(1.64,3.36,5.36)	(1.18,3.00,5.00)	(4.45,6.45,8.00)
High-tech exports	C_{19}	(5.00,7.00,8.45)	(5.73,7.73,9.00)	(4.27,6.27,7.91)	(4.18,6.09,7.64)	(2.82,4.82,6.64)	(3.55,5.55,7.27)	(0.82,2.45,4.45)	(0.73,2.45,4.45)	(3.00,4.82,6.55)
Basic research	C_{20}	(5.18,7.18,8.64)	(5.36,7.36,8.73)	(5.36,7.36,8.73)	(5.00,7.00,8.45)	(2.82,4.82,6.73)	(4.82,6.82,8.27)	(1.00,2.64,4.64)	(0.64,2.27,4.27)	(3.00,4.82,6.55)
Scientific articles	C_{21}	(5.73,7.73,9.09)	(5.36,7.36,8.73)	(5.55,7.55,8.91)	(5.36,7.36,8.73)	(2.09,3.91,5.82)	(4.09,6.09,7.73)	(0.73,2.27,4.27)	(0.36,1.73,3.73)	(3.55,5.36,7.00)
Patents granted to residents	C_{22}	(4.45,6.45,8.00)	(6.09,8.09,9.27)	(5.55,7.55,8.91)	(4.00,5.91,7.45)	(2.09,3.91,5.82)	(3.55,5.55,7.27)	(1.00,2.64,4.64)	(0.55,2.09,4.09)	(3.18,5.00,6.73)
Securing patents abroad	C_{23}	(4.73,6.64,8.09)	(6.09,8.09,9.27)	(5.55,7.55,8.91)	(3.91,5.91,7.55)	(2.27,4.09,5.91)	(3.00,5.00,6.82)	(0.73,2.27,4.27)	(0.55,2.09,4.09)	(2.30,4.00,5.90)

Table 5. The normalized fuzzy-decision matrix.

		A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Higher education achievement	C_1	(0.63,0.84,0.98)	(0.56,0.77,0.96)	(0.58,0.79,0.96)	(0.53,0.74,0.92)	(0.40,0.66,0.92)	(0.34,0.56,0.80)	(0.23,0.47,0.77)	(0.22,0.47,0.77)	(0.31,0.53,0.78)
Total public expenditure on education	C_2	(0.56,0.76,0.93)	(0.52,0.74,0.93)	(0.42,0.64,0.84)	(0.45,0.66,0.88)	(0.33,0.59,0.86)	(0.35,0.56,0.79)	(0.22,0.45,0.73)	(0.18,0.42,0.72)	(0.26,0.47,0.72)
Science degrees	C_3	(0.44,0.65,0.84)	(0.50,0.72,0.91)	(0.50,0.72,0.90)	(0.45,0.66,0.85)	(0.37,0.64,0.90)	(0.38,0.63,0.86)	(0.22,0.45,0.73)	(0.12,0.34,0.64)	(0.38,0.60,0.85)
Language skills	C_4	(0.65,0.86,1.00)	(0.28,0.50,0.72)	(0.34,0.56,0.76)	(0.57,0.78,0.95)	(0.49,0.76,1.00)	(0.30,0.54,0.78)	(0.14,0.36,0.66)	(0.36,0.64,0.93)	(0.49,0.74,0.98)
Value of society	C_5	(0.50,0.71,0.90)	(0.33,0.54,0.75)	(0.34,0.56,0.76)	(0.49,0.70,0.90)	(0.40,0.66,0.93)	(0.26,0.49,0.73)	(0.42,0.69,0.99)	(0.28,0.55,0.85)	(0.32,0.56,0.81)
Youth interest in science	C_6	(0.39,0.59,0.79)	(0.42,0.64,0.83)	(0.46,0.68,0.88)	(0.32,0.53,0.74)	(0.33,0.59,0.86)	(0.43,0.67,0.90)	(0.27,0.55,0.85)	(0.24,0.53,0.82)	(0.49,0.74,0.99)
Flexibility and adaptability	C_7	(0.46,0.67,0.86)	(0.38,0.60,0.80)	(0.54,0.75,0.94)	(0.57,0.78,0.96)	(0.35,0.61,0.88)	(0.35,0.58,0.81)	(0.42,0.69,0.99)	(0.38,0.66,0.96)	(0.40,0.65,0.89)
Technological cooperation	C_8	(0.50,0.71,0.89)	(0.52,0.74,0.94)	(0.46,0.68,0.87)	(0.51,0.72,0.90)	(0.33,0.59,0.86)	(0.29,0.52,0.76)	(0.20,0.47,0.77)	(0.20,0.50,0.80)	(0.38,0.63,0.88)
Knowledge transfer	C_9	(0.54,0.75,0.92)	(0.52,0.74,0.93)	(0.50,0.71,0.91)	(0.47,0.68,0.87)	(0.33,0.59,0.86)	(0.31,0.54,0.78)	(0.18,0.45,0.74)	(0.20,0.50,0.80)	(0.38,0.63,0.88)
Development an application of technology	C_{10}	(0.54,0.75,0.92)	(0.52,0.74,0.92)	(0.50,0.72,0.92)	(0.47,0.68,0.88)	(0.31,0.57,0.82)	(0.31,0.54,0.78)	(0.16,0.42,0.72)	(0.12,0.39,0.69)	(0.35,0.60,0.85)
Overall productivity	C_{11}	(0.59,0.80,0.97)	(0.60,0.81,1.00)	(0.62,0.83,1.00)	(0.61,0.82,0.98)	(0.42,0.69,0.95)	(0.43,0.67,0.88)	(0.27,0.55,0.85)	(0.24,0.53,0.82)	(0.42,0.67,0.91)
Compensation levels	C_{12}	(0.59,0.80,0.96)	(0.46,0.68,0.88)	(0.44,0.66,0.87)	(0.55,0.76,0.93)	(0.37,0.64,0.90)	(0.25,0.49,0.74)	(0.26,0.53,0.82)	(0.18,0.45,0.74)	(0.24,0.47,0.72)
Working hours	C_{13}	(0.54,0.75,0.93)	(0.46,0.68,0.87)	(0.40,0.60,0.78)	(0.47,0.68,0.87)	(0.47,0.73,0.98)	(0.37,0.60,0.82)	(0.43,0.72,1.00)	(0.42,0.72,1.00)	(0.39,0.63,0.86)
Total expenditure on R&D per capita	C_{14}	(0.46,0.67,0.87)	(0.60,0.81,0.99)	(0.44,0.66,0.86)	(0.43,0.64,0.86)	(0.30,0.57,0.83)	(0.49,0.74,0.96)	(0.30,0.58,0.88)	(0.22,0.50,0.80)	(0.31,0.53,0.78)
Business expenditure on R&D per capita	C_{15}	(0.50,0.71,0.90)	(0.54,0.75,0.94)	(0.42,0.64,0.85)	(0.39,0.61,0.81)	(0.33,0.59,0.86)	(0.41,0.65,0.87)	(0.28,0.55,0.85)	(0.24,0.53,0.82)	(0.28,0.51,0.76)
Total R&D personnel nationwide per capita	C_{16}	(0.46,0.67,0.87)	(0.48,0.70,0.90)	(0.52,0.74,0.92)	(0.34,0.55,0.75)	(0.31,0.57,0.83)	(0.27,0.49,0.73)	(0.26,0.53,0.82)	(0.22,0.50,0.80)	(0.28,0.49,0.74)
Total R&D personnel in business per capita	C_{17}	(0.54,0.75,0.92)	(0.50,0.72,0.90)	(0.44,0.66,0.85)	(0.43,0.64,0.84)	(0.31,0.57,0.83)	(0.30,0.52,0.76)	(0.28,0.55,0.85)	(0.24,0.53,0.82)	(0.30,0.51,0.75)
Qualified engineers	C_{18}	(0.65,0.86,0.98)	(0.62,0.83,0.97)	(0.58,0.79,0.94)	(0.66,0.88,1.00)	(0.52,0.78,1.00)	(0.38,0.63,0.85)	(0.24,0.50,0.80)	(0.18,0.45,0.74)	(0.56,0.81,1.00)
High-tech exports	C_{19}	(0.52,0.73,0.88)	(0.62,0.83,0.97)	(0.46,0.68,0.85)	(0.44,0.64,0.81)	(0.37,0.64,0.88)	(0.43,0.67,0.88)	(0.12,0.36,0.66)	(0.11,0.36,0.66)	(0.38,0.60,0.82)
Basic research	C_{20}	(0.54,0.75,0.90)	(0.58,0.79,0.94)	(0.58,0.79,0.94)	(0.53,0.74,0.89)	(0.37,0.64,0.89)	(0.58,0.82,1.00)	(0.15,0.39,0.69)	(0.09,0.34,0.64)	(0.38,0.60,0.82)
Scientific articles	C_{21}	(0.59,0.80,0.94)	(0.58,0.79,0.94)	(0.60,0.81,0.96)	(0.57,0.78,0.92)	(0.28,0.52,0.77)	(0.49,0.74,0.93)	(0.11,0.34,0.64)	(0.05,0.26,0.55)	(0.44,0.67,0.88)
Patents granted to residents	C_{22}	(0.46,0.67,0.83)	(0.66,0.87,1.00)	(0.60,0.81,0.96)	(0.42,0.63,0.79)	(0.28,0.52,0.77)	(0.43,0.67,0.88)	(0.15,0.39,0.69)	(0.08,0.31,0.61)	(0.40,0.63,0.84)
Securing patents abroad	C_{23}	(0.49,0.69,0.84)	(0.66,0.87,1.00)	(0.60,0.81,0.96)	(0.41,0.63,0.80)	(0.30,0.54,0.78)	(0.36,0.60,0.82)	(0.11,0.34,0.64)	(0.08,0.31,0.61)	(0.29,0.50,0.74)

Table 6. The weighted normalized fuzzy-decision matrix.

		A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Higher education achievement	C_1	(0.001,0.005,0.015)	(0.001,0.005,0.015	(0.001,0.005,0.015)	(0.001,0.004,0.014)	(0.001,0.004,0.014)	(0.001,0.003,0.012)	(0.001,0.003,0.012)	(0.001,0.003,0.012)	(0.001,0.003,0.012)
Total public expenditure on education	C_2	(0.002,0.007,0.021)	(0.002,0.006,0.021)	(0.001,0.006,0.019)	(0.002,0.006,0.020)	(0.001,0.005,0.019)	(0.001,0.005,0.018)	(0.001,0.004,0.016)	(0.001,0.004,0.016)	(0.001,0.004,0.016)
Science degrees	C_3	(0.002,0.008,0.025)	(0.002,0.008,0.027)	(0.002,0.008,0.027)	(0.002,0.008,0.025)	(0.002,0.007,0.027)	(0.002,0.007,0.025)	(0.001,0.005,0.022)	(0.001,0.004,0.019)	(0.002,0.007,0.025)
Language skills	C_4	(0.002,0.008,0.024)	(0.001,0.005,0.017)	(0.001,0.005,0.018)	(0.002,0.007,0.022)	(0.002,0.007,0.024)	(0.001,0.005,0.018)	(0.000,0.003,0.016)	(0.001,0.006,0.022)	(0.002,0.007,0.023)
Value of society	C_5	(0.002,0.007,0.023)	(0.001,0.006,0.019)	(0.002,0.006,0.019)	(0.002,0.007,0.023)	(0.002,0.007,0.024)	(0.001,0.005,0.018)	(0.002,0.007,0.025)	(0.001,0.006,0.022)	(0.001,0.006,0.020)
Youth interest in science	C_6	(0.003,0.010,0.032)	(0.003,0.011,0.034)	(0.003,0.011,0.036)	(0.002,0.009,0.030)	(0.002,0.010,0.035)	(0.003,0.011,0.036)	(0.002,0.009,0.034)	(0.002,0.009,0.033)	(0.003,0.012,0.040)
Flexibility and adaptability	C_7	(0.004,0.014,0.044)	(0.003,0.012,0.041)	(0.005,0.016,0.048)	(0.005,0.016,0.049)	(0.003,0.013,0.045)	(0.003,0.012,0.041)	(0.004,0.014,0.050)	(0.003,0.014,0.049)	(0.003,0.013,0.045)
Technological cooperation	C_8	(0.004,0.014,0.043)	(0.004,0.015,0.046)	(0.004,0.013,0.042)	(0.004,0.014,0.044)	(0.003,0.012,0.042)	(0.002,0.010,0.037)	(0.002,0.009,0.038)	(0.002,0.010,0.039)	(0.003,0.012,0.043)
Knowledge transfer	C_9	(0.002,0.006,0.019)	(0.002,0.006,0.020)	(0.002,0.006,0.019)	(0.002,0.006,0.018)	(0.001,0.005,0.018)	(0.001,0.005,0.016)	(0.001,0.004,0.016)	(0.001,0.004,0.017)	(0.001,0.005,0.018)
Development an application of technology	C_{10}	(0.002,0.007,0.023)	(0.002,0.007,0.023)	(0.002,0.007,0.023)	(0.002,0.007,0.021)	(0.001,0.005,0.020)	(0.001,0.005,0.019)	(0.001,0.004,0.017)	(0.000,0.004,0.017)	(0.001,0.006,0.021)
Overall productivity	C_{11}	(0.001,0.003,0.011)	(0.001,0.004,0.011)	(0.001,0.004,0.011)	(0.001,0.004,0.011)	(0.001,0.003,0.010)	(0.001,0.003,0.010)	(0.000,0.002,0.009)	(0.000,0.002,0.009)	(0.001,0.003,0.010)
Compensation levels	C_{12}	(0.004,0.012,0.041)	(0.003,0.011,0.037)	(0.003,0.010,0.037)	(0.003,0.012,0.040)	(0.002,0.010,0.038)	(0.002,0.008,0.031)	(0.002,0.008,0.035)	(0.001,0.007,0.031)	(0.001,0.007,0.030)
Working hours	C_{13}	(0.006,0.022,0.071)	(0.005,0.020,0.066)	(0.004,0.018,0.060)	(0.005,0.020,0.066)	(0.005,0.022,0.074)	(0.004,0.018,0.063)	(0.005,0.021,0.076)	(0.005,0.021,0.076)	(0.004,0.018,0.066)
Total expenditure on R&D per capita	C_{14}	(0.033,0.093,0.233)	(0.042,0.113,0.266)	(0.031,0.091,0.232)	(0.030,0.089,0.230)	(0.021,0.078,0.223)	(0.035,0.102,0.257)	(0.021,0.080,0.236)	(0.015,0.069,0.214)	(0.022,0.074,0.211)
Business expenditure on R&D per capita	C_{15}	(0.042,0.117,0.289)	(0.046,0.124,0.303)	(0.036,0.105,0.275)	(0.033,0.100,0.260)	(0.027,0.097,0.276)	(0.034,0.107,0.280)	(0.024,0.091,0.275)	(0.021,0.087,0.266)	(0.024,0.084,0.245)
Total R&D personnel nationwide per capita	C_{16}	(0.010,0.027,0.068)	(0.010,0.028,0.071)	(0.011,0.029,0.072)	(0.007,0.022,0.059)	(0.007,0.023,.065)	(0.006,0.020,0.057)	(0.005,0.021,0.065)	(0.005,0.020,0.063)	(0.006,0.019,0.058)
Total R&D personnel in business per capita	C_{17}	(0.012,0.033,0.081)	(0.011,0.032,0.080)	(0.010,0.029,0.076)	(0.010,0.028,0.074)	(0.007,0.025,0.074)	(0.007,0.023,0.067)	(0.007,0.024,0.076)	(0.006,0.023,0.073)	(0.007,0.023,0.067)
Qualified engineers	C_{18}	(0.006,0.016,0.036)	(0.006,0.015,0.036)	(0.006,0.015,0.035)	(0.006,0.016,0.037)	(0.005,0.014,0.037)	(0.004,0.011,0.031)	(0.002,0.009,0.029)	(0.002,0.008,0.027)	(0.005,0.015,0.037)
High-tech exports	C_{19}	(0.038,0.113,0.273)	(0.046,0.130,0.302)	(0.034,0.105,0.265)	(0.033,0.100,0.251)	(0.028,0.099,0.274)	(0.032,0.104,0.273)	(0.009,0.057,0.206)	(0.008,0.057,0.206)	(0.028,0.094,0.254)
Basic research	C_{20}	(0.031,0.088,0.216)	(0.033,0.094,0.227)	(0.033,0.094,0.227	(0.030,0.088,0.215)	(0.022,0.076,0.215)	(0.034,0.098,0.241)	(0.009,0.047,0.166)	(0.005,0.040,0.153)	(0.022,0.071,0.197)
Scientific articles	C_{21}	(0.025,0.072,0.187)	(0.024,0.072,0.187	(0.025,0.074,0.190)	(0.023,0.070,0.183)	(0.011,0.047,0.153)	(0.020,0.067,0.185)	(0.004,0.031,0.126)	(0.002,0.023,0.110)	(0.018,0.061,0.173)
Patents granted to residents	C_{22}	(0.008,0.025,0.070)	(0.012,0.033,0.084)	(0.011,0.031,0.081)	(0.008,0.024,0.066)	(0.005,0.020,0.065)	(0.008,0.025,0.074)	(0.003,0.015,0.058)	(0.001,0.012,0.051)	(0.007,0.024,0.071)
Securing patents abroad	C_{23}	(0.005,0.015,0.040)	(0.007,0.019,0.047)	(0.006,0.017,0.046)	(0.004,0.013,0.038)	(0.003,0.012,0.037)	(0.004,0.013,0.039)	(0.001,0.007,0.030)	(0.001,0.007,0.029)	(0.003,0.011,0.035)

We define $\widetilde{CC}_i^-$ as the satisfaction degree in the *i-th* alternative and $\widetilde{CC}_i^+$ as the gap degree in *i-th* alternative. We can determine which and how gaps should be improved for achieving aspiration levels and obtaining the best win-win strategy from among a fuzzy set of feasible alternatives. The aspired/desired satisfaction degree of the fuzzy TOPSIS is 1.00. The results presented in Table 7 indicate that we can determine the satisfaction degrees and gap degrees of each company. Thereafter, the satisfaction degree values of A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8, and A_9 are the 0.0505, 0.0532, 0.0500, 0.0480, 0.0474, 0.0491, 0.0423, 0.0401, and 0.0452 levels, respectively (i.e., the 0.950, 0.947, 0.950, 0.952, 0.953, 0.951, 0.958, 0.960, and 0.955 levels, respectively, should be improved). However, we can calculate the gap degrees between the performance and the aspired/desired level using Equation (16). The results presented in Table 7 reveal that Singapore (A_1), South Korea (A_2), and Taiwan (A_3) are similar to the aspired/desired level.

Table 7. Closeness coefficients to the aspired level among the different countries.

Countries		d_i^+	d_i^-	Gap Degree of CC_i^+	Satisfaction Degree of CC_i^-
Singapore	A_1	22.074	1.174	0.950	0.0505
South Korea	A_2	22.021	1.237	0.947	0.0532
Taiwan	A_3	22.088	1.163	0.950	0.0500
Hong Kong	A_4	22.127	1.115	0.952	0.0480
Malaysia	A_5	22.168	1.104	0.953	0.0474
China	A_6	22.118	1.143	0.951	0.0491
Thailand	A_7	22.283	0.984	0.958	0.0423
Philippines	A_8	22.328	0.934	0.960	0.0401
India	A_9	22.200	1.052	0.955	0.0452

5. Conclusions

The present study adopted AHP and TOPSIS of MCDM to evaluate the HRST performance in Southeast Asian countries. The TOPSIS results indicate that Singapore, South Korea, and Taiwan have similar aspired/desired levels. That is, these countries have excellent HRST performance. Human resource competitiveness is the most important factor in achieving national competitiveness. The 2010 World Competitiveness Scoreboard ranked 58 economies covered in the International Institute for Management Development [5] World Competitiveness Yearbook. For the first time in decades, Singapore was ranked 1st (scoreboard = 100). Singapore had high HRST performance, thereby indicating the highest competitiveness. Taiwan and South Korea also had high HRST performance and can rapidly improve their national competitiveness. Taiwan's rank increased from 23rd to 8th, while South Korea's rank increased from 27th to 23rd. Therefore, high HRST performance enables modern economies to improve national competitiveness.

The AHP result identified important criteria for evaluating HRST performance, namely, business R&D per capita expenditures, high-tech exports, total R&D per capita expenditures, basic research, and total R&D personnel per capita nationwide. Countries can enhance their HRST performance by increasing their R&D investment and education of R&D personnel. The main determinant of innovation is formal knowledge resulting from R&D or from the acquisition of equipment, patents, or licenses (Musolesi & Huiban, 2012). Moreover, a country should focus on high-tech and research output indicators to improve national compositeness.

The present study contributes to the current knowledge in several ways. First, HRST is a core competitive advantage for any country in the current global environment. The application of fuzzy TOPSIS to rank Southeast Asian countries by HRST performance enables this study to provide guidance for these countries to develop their national competitiveness. Moreover, improving HRST performance means enhancing a country's human resource competitiveness and increasing the level of economic development. Second, this study applies the fuzzy AHP methods to identify which indicators are the most important in the development of HRST performance and provides implications for allocating resources in HRST development. Given that resources are scarce, additional resources can be invested in the most important HRST variables. Third, the current ranking of national competitiveness is limited only to overall performance. The present study ranks Southeast Asian countries in terms of HRST. Thus, this research clarifies the competitiveness of a country with regard to HRST. Lastly, combining the results of the fuzzy AHP and fuzzy TOPSIS enables this study to provide a comprehensive understanding of the important weight of each HRST criteria and the Southeast Asian country ranking.

Further research can explore how to substantially remove the gaps between each criterion on the basis of a network relationship map (NRM) and identify the complex relationships among the evaluation criteria. Accordingly, NRM can identify the most important criteria and assess the relationships among the evaluation criteria.

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