Collaboration with Industry in Chinese Higher Education: Evaluation Based on a Matter-element Model

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Abstract

The present paper aims to construct a comprehensive evaluation system and propose an effective, objective method to evaluate the quality of university-industry collaboration. First, based on total quality management theory, an evaluation index system or complex is designed to cover the whole progression of input, process, and output of UIC. Second, the analytic hierarchical process is employed to calculate the weights of the indexes, and an evaluation matter-element model is developed to assess UIC quality levels on the concrete indexes. There are two main advantages of the UIC evaluation matter-element model: (1) It makes deep comparison of the indexes achieving the same evaluation level among different UICs; (2) It discovers the possibility of being converted into the corresponding level on a certain index based on K-values. Finally, four UICs in China were assessed by employing the matter-element evaluation tool developed in this research, and make further comparisons of the four UICs.

Keywords

Analytic hierarchical process, a matter-element model, evaluation index system, higher education, university-industry collaboration

1. Introduction

In the context of the global economy, apart from the traditional roles of teaching and researching played by universities, the ‘third role’ of higher education has been increasingly emphasized: collaboration with industry in the service of social and economic development (Borah, Massini, & Malik, 2023). There are two kinds of academic institutions presently taking responsibility for collaboration with industry in China: universities and higher vocational education schools (HVES). Major benefits of university-industry collaboration (UIC) include facilitating the transfer of basic research into productive sectors (Huang and Xiong, 2023), training undergraduates through internship programs, and also streaming individuals into good jobs in industry (Fernandes et al., 2023), etc.

The quality of UIC is a crucial factor in guaranteeing the successful implementation of collaboration. It is, naturally, important to evaluate and measure the effectiveness of UIC, which is the key step to identifying significant aspects of UIC contributing to collaboration activities and discovering unqualified content to further improve. There has been increasing interest in assessing the quality of UIC in recent years (Scandura, 2016). However, the existing evaluation tools only focus on certain forms and parts of UIC, lacking the assessment of the whole process of UIC. Therefore, it is urgent to construct a comprehensive evaluation system to guarantee all forms and parts of UIC are assessed. The objective of this research is to design a comprehensive evaluation index system covering the input, process, and output of UIC. Furthermore, the analytic hierarchical process (AHP) is employed to calculate the weights of indexes.
and matter-element analysis is employed to obtain an overall evaluation grade and grades of lower-level indexes.

2. Method

There are three steps to constructing an evaluation matter-element model for the assessment of UIC.

2.1 Construction of evaluation index system

To assess each part and the two forms of UIC, we develop a comprehensive evaluation index system covering the whole process of UIC and incorporating both the knowledge transfer and talent cultivation elements based on Total Quality Management (TQM) theory (Riaz et al., 2023).

First, we categorized the explored indicators, which constitute 88 third-level indexes in the evaluation system. Second, based on the third-level indexes, 24 relevant second-level indexes were clustered into first-level indexes. Finally, we developed an integrated evaluation index system encompassing seven first-level indexes through combining first-level indexes reflecting similar aspects of UIC.

2.2 Calculation of index weights based on the AHP

The AHP developed by Thomas Saaty, has been widely used in the determination of grades on indexes (Saaty, 1980). In this study, the AHP method is employed to calculate the weights of evaluation indexes within the given level. As AHP methodology, the concrete steps are introduced as follows.

Firstly, a multi-level hierarchical structure was developed in Super Decision software (www.superdecisions.com), including seven first-level indexes and corresponding second-level indexes. Next, the Delphi method was employed to make the pairwise comparison (Saaty, 1980). In this study, six experts participating in UIC research and projects were invited to make comparisons between each pair of indexes at the same level using the assessment scale (1-9). Three rounds of discussion produced relatively consistent final comparison results, which were put into the Super Decision software to conduct a consistency test and calculate the weights of indexes. Fourth, consistency ratios (CRs) were used to estimate consistency; if the CR was less than 0.1, the pairwise comparison was acceptable. All the values of CR of first-level indexes and seven modules in this study were less than 0.1, as indeed it proved to be for all first-level indexes and modules in this study (Saaty, 1980).

2.3 The matter-element analysis

Matter-element analysis theory is primarily used to study the problem of incompatibility. The matter-element model can be introduced to research and solve the multi-source data decision-making from both qualitative and quantitative perspectives. The construction of matter-element model can be summarized in the following specific steps (Cai, 1994).

Step 1: Matter-element definition. An ordered triple \( R = (N, c, v) \) is defined as the matter-element, which is a combination of the object \( N \), characteristic \( c \), and value \( v \).

\[
R = [N, c, v] = [c_1, v_1; c_2, v_2; ...; c_n, v_n]
\]

In this study, \( N \) stands for the 7 first-level indexes and 24 second-level indexes, each of which is an independent matter-element; \( c \) stands for the corresponding lower level of indexes; \( v \) stands for the concrete value of the index; and \( n \) stands for the number of lower-level indexes in the corresponding first- and second-level index.

Step 2: Classical domain and segmented domain. The classical domain \( (R) \) of the matter-element matrix is the value range of each index within the corresponding grade. In this study, it includes four grades: excellent, good, qualified, and unqualified. The range of excellent grades is as follows.

\[
R = (N, c_j, v_j) = [c_1, v_1; c_2, v_2; ...; c_n, v_n]
\]

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Where \( N_j \) is the quality of UIC of grade \( j \) (it includes four grades that are excellent, good, qualified, unqualified). \( c_i \) refers to the second-level indexes in each module. \( v_{ji} (a_{pi}, b_{pi}) \) is the classical domain that represents the range of \( c_i \) on grade \( j \). The classical domains of all indexes in this study are fixed-mark ranges of four grades (excellent: [90, 100]; good: [80, 89]; qualified: [60, 79]; unqualified: [0, 59]).

Segment domain \((R_p)\) can be achieved according to indexes’ mark ranges between minimum and maximum. In this study, the segment domains of all indexes are from 0 to 100.

\[
P, c, v_{p1} \quad P, c, < a_{p1}, b_{p1} > \\
P, c, v_{p2} = [ \quad c, v_{p2} > [ \quad c, < a_{p2}, b_{p2} > ] \\
\ldots \ldots \ldots \ldots \ldots \ldots \ldots \\
c, v_{pn} = [ \quad c, < a_{pn}, b_{pn} > ]
\]

Where \( P \) represents the entire grades of UIC quality and \( v_{pn} \) is the entire grade range from the minimum of unqualified grade to the maximum of excellent grade.

**Step 3**: Determination of correlation function. The relation between concrete index \( i \) and grade \( j \) can be described by the correlation function, as follows.

\[
K_i (v_{ji}) = \rho \frac{(a_{pi}, v_{ji})}{(a_{pi}, v_{pi})} - \rho \frac{(a_{pi}, v_{ji})}{}, (1)
\]

where

\[
\rho (v_{pi}, v_{ji}) = |v_i - \frac{1}{2}(a_{ji} + b_{ji})| - \frac{1}{2}(b_{ji} - a_{ji}) , (2)
\]

\[
\rho (v_{pi}, v_{pi}) = |v_i - \frac{1}{2}(a_{pi} + b_{pi})| - \frac{1}{2}(b_{pi} - a_{pi}) , (3)
\]

where \( a_{pi} \) and \( b_{pi} \) are the minimum and maximum of the classical domain of grade \( j \) respectively. The value range of each grade has been provided above. In this study, \( a_{pi} = 0 \) and \( b_{pi} = 100 \); \( v_{i} \) is the concrete value of the index obtained from actual evaluation.

**Step 4**: Determination of degree of correlation. The four grades’ correlation degree \( K \) for the first-level indexes and seven modules can be calculated by Formula (4).

\[
K_{j} (N) = \sum_{i=1}^{n} a_i K_i (v_{ji}) , (4)
\]

Where \( K_{j} (N) \) is the degree of correlation of grade \( j \) and \( a_i \) represents the weight of the index, which is obtained by the AHP.

**Step 5**: Determining evaluation grade. The final grade is calculated according to the comprehensive correlation degree, according to the maximum correlative degree principle, that is,

\[
K_{j} = \max K_{j} (N) \quad (5)
\]

Maximum correlative degree not only implies the grade, but also it could tell us degrees belong to that grade. Thus, we can further compare two indexes belonging to the same grade based on their correlation degree, deciding which index is better.

### 3. Data Collection and Results

In order to make an intuitionistic comparison, four kinds of UIC in China involving manufacturing and services industries were chosen. We would sort them and make concrete comparisons between these four UICs. We chose two UICs from universities—C-UIC and I-UIC, focusing on knowledge transfer—and two from HVES—M-UIC and L-UIC, focusing on talent cultivation. Then, we took the original evaluation mark values for each secondary index and put values into formulas (1) (2) (3) (4) to calculate \( K \)-values; on this basis, we obtained the quality grades of the first-level indexes, modules, and overall model according to formula (5).

As seen in Table 1, C-UIC, M-UIC, and L-UIC all obtain excellent grades, and I-UIC a good grade, on the overall evaluation. L-UIC has the best performance (9.825). In order to further compare the four UICs, we next compared \( K \)-values and grades from three perspectives. First, on the knowledge transfer module, C-UIC and I-UIC received
excellent grades on the effect index; C-UIC (0.647) has a better knowledge transfer effect than I-UIC (0.159). Second, on the practical training module, M-UIC (2.643) and L-UIC (2.863) both achieved excellent grades, while C-UIC and I-UIC scored worse—showing trainee attitudes that were not positive (qualified grade). From the perspective of training guarantee, C-UIC and I-UIC were both unqualified. Moreover, the capabilities and participation of firm mentors for training talents are also unqualified, especially for C-UIC, which has a very low K-value on this index. Finally, on the benefits module, I-UIC reached a good grade, while the other three were all unqualified. More specifically, C-UIC and I-UIC achieved good grades on the university benefit index, while M-UIC and L-UIC were unqualified on all three benefit indexes (university, firm, and society). It is worth mentioning that all UICs failed to achieve social benefit.

Table 1. K-values and grades of four UICs on modules and first-level indexes

<table>
<thead>
<tr>
<th>Second level index</th>
<th>C-UIC</th>
<th>Grade</th>
<th>M-UIC</th>
<th>Grade</th>
<th>L-UIC</th>
<th>Grade</th>
<th>I-UIC</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management process</td>
<td>0.595</td>
<td>Excellent</td>
<td>0.000</td>
<td>Excellent</td>
<td>1.000</td>
<td>Excellent</td>
<td>0.028</td>
<td>Qualified</td>
</tr>
<tr>
<td>Management administrator</td>
<td>-0.128</td>
<td>Unqualified</td>
<td>0.043</td>
<td>Excellent</td>
<td>0.860</td>
<td>Excellent</td>
<td>0.042</td>
<td>Qualified</td>
</tr>
<tr>
<td>Permanent assets</td>
<td>0.201</td>
<td>Good</td>
<td>1.000</td>
<td>Excellent</td>
<td>1.000</td>
<td>Excellent</td>
<td>0.294</td>
<td>Qualified</td>
</tr>
<tr>
<td>Funds investment</td>
<td>0.629</td>
<td>Excellent</td>
<td>0.728</td>
<td>Excellent</td>
<td>0.676</td>
<td>Excellent</td>
<td>0.141</td>
<td>Unqualified</td>
</tr>
<tr>
<td>Capabilities and participation of firm mentors</td>
<td>0.996</td>
<td>Unqualified</td>
<td>0.031</td>
<td>Good</td>
<td>-0.219</td>
<td>Excellent</td>
<td>0.101</td>
<td>Unqualified</td>
</tr>
<tr>
<td>Capabilities of university faculty</td>
<td>0.418</td>
<td>Excellent</td>
<td>0.139</td>
<td>Excellent</td>
<td>0.828</td>
<td>Excellent</td>
<td>0.111</td>
<td>Qualified</td>
</tr>
<tr>
<td>Participation of university faculty</td>
<td>0.339</td>
<td>Excellent</td>
<td>-0.156</td>
<td>Good</td>
<td>0.801</td>
<td>Excellent</td>
<td>0.006</td>
<td>Good</td>
</tr>
<tr>
<td>Guarantee</td>
<td>0.270</td>
<td>Excellent</td>
<td>0.363</td>
<td>Excellent</td>
<td>0.551</td>
<td>Excellent</td>
<td>0.065</td>
<td>Excellent</td>
</tr>
<tr>
<td>Process</td>
<td>0.444</td>
<td>Excellent</td>
<td>-0.020</td>
<td>Good</td>
<td>0.406</td>
<td>Excellent</td>
<td>-0.071</td>
<td>Qualified</td>
</tr>
<tr>
<td>Effect</td>
<td>0.647</td>
<td>Excellent</td>
<td>0.469</td>
<td>Unqualified</td>
<td>0.469</td>
<td>Unqualified</td>
<td>0.159</td>
<td>Good</td>
</tr>
<tr>
<td>Barriers</td>
<td>-0.075</td>
<td>Excellent</td>
<td>0.018</td>
<td>Qualified</td>
<td>1.00</td>
<td>Excellent</td>
<td>0.202</td>
<td>Good</td>
</tr>
<tr>
<td>Training guarantee</td>
<td>0.178</td>
<td>Unqualified</td>
<td>0.448</td>
<td>Excellent</td>
<td>0.271</td>
<td>Excellent</td>
<td>-0.152</td>
<td>Unqualified</td>
</tr>
<tr>
<td>Trainee’s attitudes</td>
<td>0.115</td>
<td>Qualified</td>
<td>0.751</td>
<td>Excellent</td>
<td>1.000</td>
<td>Excellent</td>
<td>0.115</td>
<td>Qualified</td>
</tr>
<tr>
<td>Practical training process</td>
<td>0.305</td>
<td>Excellent</td>
<td>1.080</td>
<td>Excellent</td>
<td>0.239</td>
<td>Excellent</td>
<td>-0.024</td>
<td>Good</td>
</tr>
<tr>
<td>Practical training performance</td>
<td>0.036</td>
<td>Unqualified</td>
<td>0.480</td>
<td>Excellent</td>
<td>0.573</td>
<td>Excellent</td>
<td>0.007</td>
<td>Good</td>
</tr>
<tr>
<td>Practical training assessment</td>
<td>0.021</td>
<td>Good</td>
<td>-0.046</td>
<td>Excellent</td>
<td>0.780</td>
<td>Excellent</td>
<td>-0.019</td>
<td>Good</td>
</tr>
<tr>
<td>Professional qualities</td>
<td>0.000</td>
<td>Qualified</td>
<td>0.088</td>
<td>Good</td>
<td>0.000</td>
<td>Excellent</td>
<td>0.161</td>
<td>Qualified</td>
</tr>
<tr>
<td>Knowledge and skill</td>
<td>0.043</td>
<td>Good</td>
<td>0.214</td>
<td>Good</td>
<td>0.793</td>
<td>Excellent</td>
<td>-0.024</td>
<td>Qualified</td>
</tr>
<tr>
<td>Work capabilities</td>
<td>0.338</td>
<td>Good</td>
<td>0.256</td>
<td>Qualified</td>
<td>0.156</td>
<td>Excellent</td>
<td>0.000</td>
<td>Good</td>
</tr>
<tr>
<td>State of health</td>
<td>0.109</td>
<td>Good</td>
<td>0.085</td>
<td>Excellent</td>
<td>0.900</td>
<td>Excellent</td>
<td>0.118</td>
<td>Good</td>
</tr>
<tr>
<td>Employment quality</td>
<td>-0.024</td>
<td>Excellent</td>
<td>0.093</td>
<td>Good</td>
<td>0.019</td>
<td>Excellent</td>
<td>0.234</td>
<td>Good</td>
</tr>
<tr>
<td>University benefits</td>
<td>-0.115</td>
<td>Good</td>
<td>0.654</td>
<td>Unqualified</td>
<td>0.070</td>
<td>Unqualified</td>
<td>-0.009</td>
<td>Good</td>
</tr>
<tr>
<td>Firm benefits</td>
<td>0.412</td>
<td>Unqualified</td>
<td>0.539</td>
<td>Unqualified</td>
<td>0.244</td>
<td>Unqualified</td>
<td>-0.050</td>
<td>Good</td>
</tr>
<tr>
<td>Social benefits</td>
<td>1.000</td>
<td>Unqualified</td>
<td>1.000</td>
<td>Unqualified</td>
<td>0.982</td>
<td>Unqualified</td>
<td>0.920</td>
<td>Unqualified</td>
</tr>
</tbody>
</table>

First level indexes

<table>
<thead>
<tr>
<th>K-values</th>
<th>Grade</th>
<th>K-values</th>
<th>Grade</th>
<th>K-values</th>
<th>Grade</th>
<th>K-values</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project management</td>
<td>0.467</td>
<td>Excellent</td>
<td>0.043</td>
<td>Excellent</td>
<td>1.860</td>
<td>Excellent</td>
<td>0.070</td>
</tr>
<tr>
<td>Physical resources</td>
<td>0.469</td>
<td>Excellent</td>
<td>1.728</td>
<td>Excellent</td>
<td>1.676</td>
<td>Excellent</td>
<td>-0.125</td>
</tr>
<tr>
<td>Human resources</td>
<td>0.068</td>
<td>Unqualified</td>
<td>-0.401</td>
<td>Good</td>
<td>1.410</td>
<td>Excellent</td>
<td>-0.234</td>
</tr>
<tr>
<td>Knowledge transfer</td>
<td>1.286</td>
<td>Excellent</td>
<td>-0.181</td>
<td>Excellent</td>
<td>1.331</td>
<td>Excellent</td>
<td>-0.392</td>
</tr>
<tr>
<td>Practical training</td>
<td>-0.980</td>
<td>Qualified</td>
<td>2.634</td>
<td>Excellent</td>
<td>2.863</td>
<td>Excellent</td>
<td>-0.578</td>
</tr>
<tr>
<td>Qualified talents</td>
<td>0.183</td>
<td>Good</td>
<td>-0.051</td>
<td>Good</td>
<td>1.868</td>
<td>Excellent</td>
<td>0.170</td>
</tr>
<tr>
<td>Benefits</td>
<td>1.073</td>
<td>Unqualified</td>
<td>2.192</td>
<td>Unqualified</td>
<td>1.292</td>
<td>Unqualified</td>
<td>-0.135</td>
</tr>
<tr>
<td>Overall evaluation</td>
<td>-2.306</td>
<td>Excellent</td>
<td>-4.807</td>
<td>Excellent</td>
<td>9.825</td>
<td>Excellent</td>
<td>-2.806</td>
</tr>
</tbody>
</table>

Notes: “Excellent”; Good”; Qualified”; Unqualified”” represent “transformation to excellent; transformation to good; transformation to qualified; transformation to unqualified”

4. Discussion

4.1 The effectiveness of the UIC evaluation matter-element tool

The matter–element evaluation method has been widely used in quality evaluation (Wang et al., 2020), and has achieved more reliable results than the traditional method. It can make deep analysis and comparison on three aspects compared to traditional evaluation tools.
First, the Delphi method was employed to assess the weights of first- and second-level indexes. Besides, the professional software (Super Decision) was employed to calculate the weights based on the evaluation results of pairwise comparisons from each expert. Second, the effective evaluation tool provides both overall evaluation results and concrete assessments on first- and second-level indexes. Given that each index has different weights, the value of each index has a diverse impact on the overall evaluation grade. The indexes with lower values are the targets to be strengthened further. Third, this evaluation tool is useful for finding the distance of the index from a certain grade. The concrete K-values make it possible to compare some of the indexes achieving the same evaluation grade among different UICs.

4.2 The concrete meaning of different K-values

The K-value characterizes the extent to which the index belongs to a certain level of criteria. Generally, there should exist one positive K-value at least among the four grades for each index. The highest K-value of the grade is the final evaluation grade of the index. The negative and positive K-values will be discussed respectively as follows.

On the one hand, K-value is an effective indicator of the quality of specific indexes, leaving us clear in principle on which of two UICs with the same grade on a certain index, is actually scoring higher. When the K-value is positive, the higher the K-value is, the greater the relevance to this grade. On the other hand, when the K-value is negative, this evaluation matter-element model could further discover the possibility that the UIC project will be converted to the corresponding grade on a certain index. The evaluation grade with an asterisk (*) indicates that it does not belong to this grade but has the possibility to transform to this grade, and the higher the K-value is, the greater the possibility of transforming to this grade.

4.3 The comparisons between four UICs in China

From the overall evaluation results, other than I-UIC, all UICs obtained excellent grades. But does this really reflect their actual performance? If we analyze the specific indexes, these three UICs all have unqualified performance on certain modules; in contrast, although I-UIC does not get an excellent overall evaluation, there are no unqualified modules. This phenomenon tells us that a closer look should be taken at unqualified indexes whose higher-level index has an excellent grade.

University and HVES play different roles in collaboration with industry. First, universities have plentiful resources and have higher scientific and technological expertise so as to perform better on knowledge transfer, while HVES are better at practical training and cultivating skilled personnel in accordance with industry needs. Second, in the process of UIC, HVES would make internship contracts with firms, which allow their students to work or practice in an authentic working environment.

Note

1. There are two kinds of institutions cooperating with industry. In order to express conveniently, we use University-industry collaboration as the expression of collaboration with industry in Chinese higher education.

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