Evaluation of Asset Performance Using Integral Data Mining Scheme

JI HUI[1] AND KUN-CHIEH WANG[2]

[1]Assets Management Department, Sanming University, Sanming 365004, China
[2]School of Mechanical and Electronic Engineering, Sanming University, Sanming 365004, China

Corresponding author: Kun-Chieh Wang (m18316252102@126.com)

ABSTRACT The asset evaluation is an indispensable process in asset management and asset disposal. Seldom studies were found in exploring asset-usage performance of laboratory equipment in universities. The influential parameters, such as source, usage, and benefit that influence the performance of asset management in universities should be considered more structurally and deeply. In this study, a structural and complete index system and an integral data mining method are proposed to investigate the effect of related index parameters on the asset-usage performance of laboratory equipment in universities. The proposed integral method includes two phases. The first phase is to find out the relative weight of each influential parameter using the integral Analytic Hierarchy Process (AHP) scheme which extensively contains the index-weight and time-weight models based on Orness measure in conjunction with the method of relative closeness degree. The second phase is to investigate the global correlation between second-level indexes and the final performance using Grey System Theory (GST). The results of case study indicate that the proposed integral AHP-and-GST method can not only be used to globally and locally understand the effect of influential parameters on fixed asset of laboratory equipment, but also provide a decision-making basis for asset allocation.

INDEX TERMS Analytic hierarchy process, asset management, grey system theory, performance evaluation, relative closeness degree.

I. INTRODUCTION AND LITERATURE REVIEW

Usually, the asset evaluation is used for pricing and asset transaction. The asset evaluation refers to assessment and estimation of its value before asset transaction transfer or change its operator. The asset evaluation is an indispensable process in asset management and asset disposal [1]–[4]. With highly attentions on the development of higher educations all over the world, governments invest much more capital in universities or colleges than ever. The major spend of college's capital lies in various assets. For a college featured with science and engineering departments, the asset of laboratory equipment takes up a major part of total funds. Conventional ways of arbitrarily allocating the asset of laboratory equipment often cause problems of asset idle, preemptive occupation, and so on. And, these matters result in the reduction of management performance of school

The associate editor coordinating the review of this manuscript and approving it for publication was Senthil Kumar.

asset. Under the constraint of limited finance budget for universities, how to efficiently use the laboratory equipment to cultivate students and perform science studies are essential. Finding a proper way to efficiently allocate the asset of laboratory equipment is an important issue in the operation and management of a university. In the past, a large amount of studies concerned problems of asset allocation [5], asset management [6], asset risk [7], and etc. in many application fields such as engineering, company, and individuals. Seldom papers were found in dealing with the asset performance evaluation of school's laboratory equipment. Thus, it is expected to find a good asset performance evaluation method for the usage of laboratory equipment in universities.

Among past proposed asset evaluation methods, there were three main streams: cost method, revenue method, and market method [8]. These methods all concerned about using the macro level scheme to evaluate assets. Some of them proposed simple or linear mathematical formulas to express the relationship between asset performance and asset usage.

TABLE 1. Performance evaluation index system of laboratory equipment assets.

unit:CNY

First-level index	unit		Second-level index
LE cost (C_1)	CNY	C_{11}	Low-value LE (<10000)
		C_{12}	Middle-value LE (10000~100000)
		C_{13}	High-value LE(>100000)
LE fund rate (C_2)	percentage	C_{21}	Funded by school
		C_{22}	Funded by government
		C_{23}	Funded by private enterprise
LE usage rate (C_3)	percentage	C_{31}	Available LE quantity
		C_{32}	Students' practice hours
		C_{33}	Undamaged rate of LE
LE benefit (C_4)	numbers	C_{41}	Project numbers
		C_{42}	Prize-winning numbers
		C_{43}	Authorization numbers of patents

Besides, many studies used the weight or modified weight methods to deal with the asset evaluation problems [9], [10]. These methods were ambiguous and insufficient to describe the complex non-linear relationship between asset-related parameters and the asset-usage performance. Besides, asset-related parameters, such as source, usage, and benefit that significantly influence the asset performance of laboratory equipment in universities, should be considered more structurally and deeply. Therefore, this study attempts to propose a structural and complete asset index system and an integral data mining method to investigate the effect of asset-related index parameters on the asset-usage performance of laboratory equipment in universities. In detail, a novel integral data mining method which includes the integral Analytic Hierarchy Process (AHP) scheme and the Grey System Theory (GST) is proposed to analyze and establish the relationship between the fixed asset performance and its influential indexes for laboratory equipment in universities.

II. PROBLEM DESCRIPTION AND FORMULATION
A. CONSTRUCTION OF INDEX SYSTEM
The asset investment of laboratory equipment (LE) is crucial for cultivation of university students. In view of the existing problem of asset allocation of LE in universities and the main factors that affect their operational performance, this study attempts to propose an effective methodology to construct a performance evaluation index system of LE, which majorly includes four-aspect indexes: LE cost, LE fund rate, LE usage rate, and LE benefit. Further, based on the necessity for cultivating students' application abilities after using LE, we consulted twenty experts who worked at asset departments of different universities and all had plentiful experiences in asset managements. And, we obtain twelve second-level performance evaluation indexes which are explained as follows and listed in Table 1.

1) LE COST
The LE cost for a university is divided into three categories according to the amount of investment (called C_{11}, C_{12}, and C_{13}) in which, C_{11} denotes the low-value equipment that has an amount lower than CNY 10000, C_{12} denotes the middle-value equipment that has an amount between CNY 10,000 and 100,000, and C_{13} denotes the middle-value equipment that has an amount over than CNY 100,000.

2) LE FUND RATE
The LE fund rate means the ratio of LE fund from certain source to total funds of school in the same year, and it can be divided into three categories as follows. C_{21} denotes the fund rate from school. C_{22} denotes the fund rate from government. C_{23} denotes the fund rate from private enterprise.

3) LE USAGE RATE
The LE usage rate includes three terms as follows. C_{31} denotes LE quantity over student numbers in a whole year. C_{32} denotes the ratio of students' practice hours in using LE to students' total learning hours in a whole year. C_{33} denotes the undamaged rate which is the ratio of undamaged numbers to the total numbers of LE in a whole year.

4) LE BENEFIT
The LE benefit includes three categories as follows. C_{41} denotes the project numbers of using LE in a whole year. C_{42} denotes the technological prize-winning numbers of students who ever used LE in a whole year. C_{43} denotes the grant authorization numbers of patents from school to enterprise in a whole year.

B. PERFORMANCE EVALUATION MODEL OF LABORATORY EQUIPMENT ASSET
In the first phase, we use the integral AHP scheme which contains the conventional AHP but integrates with the relative closeness degree as the judgement evaluation index to investigate the influence of various indexes of LE asset on the asset performance. In the second phase, we use the GM(1,N) model of GST scheme to obtain a non-linear relationship between indexes of LE asset and asset performance.

1) AHP METHOD

To deal with the asset performance evaluation problem, several different methods have been proposed such as neural network [11], [12], analytic hierarchy process [13], fuzzy logic [14], and etc. The most extensively used method is AHP decision-making method by Satty in 1980. AHP is a powerful tool in solving decision-making problems and has been successfully applied to many fields [15]–[17]. It enables decision makers to handle unstructured and complex problems in a hierarchy way for determining the priorities in a systematic manner. AHP uses pair-wise comparisons and derives priorities among all the criteria and sub-criteria within each level. AHP combines the criteria weights and option scores to obtain a global score for a consequent ranking. The higher weight means more important the corresponding criterion is. And the higher score means the better performance of the option is.

2) GREY SYSTEM THEOREM (GST)

GST, firstly proposed by Julong Deng in 1982 [18], is a method that focuses on the investigation of problems involving small samples or poor information. It may be used to deal with uncertain systems that have partially known data. Through generating, excavating and extracting useful data, the behavior of system can be correctly described and effectively monitored. As known, there always exist lots of uncertain systems with small samples and poor information. This fact motivates the wide range of applicability of GST.

In this study, the GM(1, N) scheme of GST [19] is used to establish the correlation relationship between LE asset indexes and final asset performance in terms of the influence weighting. Basically, the GM(1,N) model adopts a first-order differential equation to establish the relationship between independent and dependent variables. Followings are a brief introduction of GM(1,N) algorithm.

1) Establishing an initial sequence:

$$z_i^{(0)}(k), \quad i = 1, 2, 3, \ldots, N \quad \text{and } k = 1, 2, 3, \ldots, n. \quad (1)$$

2) Generating a new sequence:

We perform the accumulated generating operation (AGO) to generate a new sequence $z_i^{(1)}(k)$ as follows.

$$AGO\{z_j^{(0)}\} = z_j^{(1)} = \{\sum_{i=1}^{1} z^{(0)}(i),$$

$$\sum_{i=1}^{2} z^{(0)}(i), \sum_{i=1}^{3} z^{(0)}(i), \ldots, \sum_{i=1}^{n} z^{(0)}(i)\}, \quad (2)$$

where

$$z_j^{(1)}(k) = \sum_{i=1}^{k} z^{(0)}(i), \quad j = 1, 2, 3, \ldots, N. \quad (3)$$

3) Establishing the correlation relationship:

It is assumed that a first-order differential equation holds true for the above two sequences:

$$\frac{dz_1^{(0)}(k)}{dt} + az_1^1(k) = q_2 z_2^{(1)}(k) + q_3 z_3^{(1)}(k) + \ldots + q_N z_N^{(1)}(k). \quad (4)$$

Equation (4) is called the GM(1,N) model.

4) Solving and obtaining the final form:

We solve the above equation by difference approximation and combine it with equation (3) to yield

$$z_1^{(0)}(k) + ay_1^{(1)}(k) = \sum_{j=2}^{N} q_j z_j^{(1)}(k), \quad (5)$$

where

$$y_1^{(1)}(k) = 0.5z_1^{(1)}(k) + 0.5z_1^{(1)}(k-1) \quad (6)$$

Equation (5) can be rearranged into a matrix form:

$$X_N = \xi Q, \quad (7)$$

where

$$X_N^T = [\, z_1^{(0)}(2) \quad z_1^{(0)}(3) \quad z_1^{(0)}(4) \quad \ldots \quad z_1^{(0)}(n)\,],$$
$$Q^T = [\, a \quad q_2 \quad q_3 \quad \ldots \quad q_N\,],$$

and

$$\xi = \begin{bmatrix} -y_1^{(1)}(2) & z_2^{(1)}(2) & \ldots & z_N^{(1)}(2) \\ -y_1^{(1)}(3) & z_2^{(1)}(3) & \ldots & z_N^{(1)}(3) \\ \vdots & & & \\ -y_1^{(1)}(n) & z_2^{(1)}(n) & \ldots & z_N^{(1)}(n) \end{bmatrix}. \quad (8)$$

5) Calculating Q

The matrix Q can be obtained by using the least-square error method as

$$Q = (\xi^T \xi)^{-1} \xi^T X_N. \quad (9)$$

Hence, the influence weighting of the major sequence (independent variables) on the target sequence (dependent variables) can be obtained by comparing the norm values of $q_2 \sim q_N$.

3) CALCULATING INDEXES OF RELATIVE CLOSENESS DEGREE

Due to insufficient ability for using traditional weighting method to handle evaluation problems, we now introduce the Index of Relative Closeness Degree (IRCD) method to more reasonably and accurately evaluate the performance of fixed asset of laboratory equipment. Conceptually, IRCD means how close or how much influences of the index parameters on the final target parameter. IRCD is comprised of normalized weights in each layer and defined as follows.

The IRCD in t^{th} year of the first-level index C_i for certain school a_s is denoted by D_{sti} and calculated as

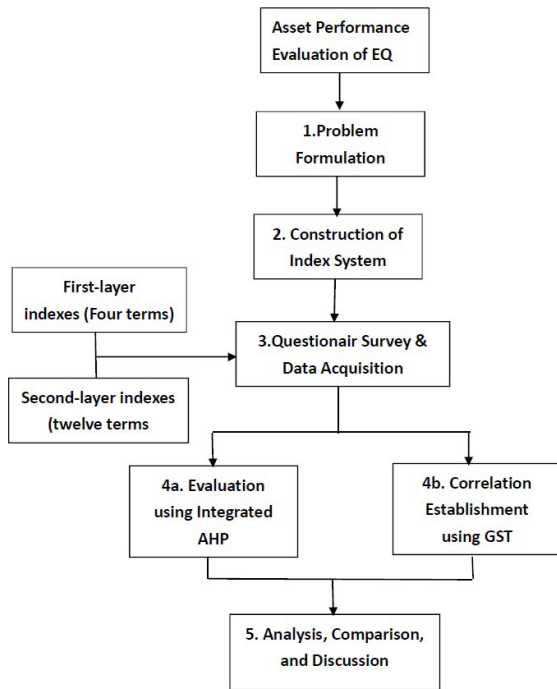$$D_{sti} = \frac{D_{sti-}}{D_{sti+} + D_{sti-}}, \quad (10)$$

FIGURE 1. Architecture of the proposed methodology.

TABLE 2. Definitions of 1-9 points in judgement scale.

Scale points	Meaning
1	The importance of horizontal index is equivalent to that of vertical index
3	The importance of horizontal index is slightly more important than that of vertical index
5	The importance of horizontal index is more important than that of vertical index
7	The importance of horizontal index is quite more important than that of vertical index
9	The importance of horizontal index is absolutely more important than that of vertical index
2,4,6,8	Between upper and lower values
Reciprocal	$a_{ji} = 1 / a_{ij}$

indexes based on the survey from experts. Third, we perform questionnaire surveys to acquire the necessary data of assessment. Fourth, we use the integral AHP and GM(1,N) models to respectively analyze and establish the correlation of the asset performance of LE. Fifth, we make analyses, comparison, and discussion. The calculation details of integral AHP are introduced as follows.

Step 1: Calculation of consistency ratio

According to the principle of AHP mentioned before, we first proceed the evaluation of C_{ij} by experts using Delphi method with 1-9 points of judgement scale (shown in Table 2). The linguistic evaluation results of experts' judgements for each criterion are transformed into pairwise comparisons. Then we may construct a pairwise comparison matrix **A** in which the intensities of importance from activity i to j is denoted by a_{ji} (i < j =1,2,3,...,n), and components $a_{ji} = 1/a_{ij}$ denote their reciprocal numbers.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & & \ddots & \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}. \qquad (17)$$

The geometric averages of weights of second-level indexes C_{ij} are defined by

$$\bar{w}_{ij} = \sqrt[n]{\prod_{k=1}^{n} a_{ijk}}. \qquad (18)$$

The normalized weights are defined by

$$w_{ij} = \frac{\bar{w}_{ij}}{\sum\limits_{j=1}^{n} \bar{w}_{ij}}. \qquad (19)$$

Hence, the weights of first-level indexes are expressed as $w_i = \begin{bmatrix} w_{i1} & w_{i2} & \cdots & w_{in} \end{bmatrix}^T$. The consistency index (η_{ci}) is defined as [16]:

$$\eta_{ci} = \frac{\lambda_{\max} - n}{n - 1}, \qquad (20)$$

where n is the order of judgement matrix **A** and $\lambda_{\max}$ is its maximal eigenvalue. The consistency ratio (η_{cr}) is defined as $\eta_{cr} = \eta_{ci}/\eta_{ri}$, where η_{ri} is the random average consistency

in which D_{sti}^{+} and D_{sti}^{-} are respectively defined as follows:

$$D_{sti}^{+} = \sqrt{\sum_{j=1}^{n} w_{ij}(x_{st,ij} - \max x_{st,ij})^2}, \qquad (11)$$

$$D_{sti}^{-} = \sqrt{\sum_{j=1}^{n} w_{ij}(x_{st,ij} - \min x_{st,ij})^2}. \qquad (12)$$

Similarly, the IRCD in t^{th} year of the second-level index C_i for certain school a_s is calculated as

$$D_{st} = \frac{D_{st-}}{D_{st+} + D_{st-}}, \qquad (13)$$

$$D_{st}^{+} = \sqrt{\sum_{i=1}^{n} w_{ij}(x_{st,i} - \max x_{st,i})^2}, \qquad (14)$$

$$D_{st}^{-} = \sqrt{\sum_{i=1}^{n} w_{ij}(x_{st,i} - \min x_{st,i})^2}. \qquad (15)$$

The final IRCD for certain school is denoted by D_s and calculated by the following formula:

$$D_s = \sum_{t=1}^{T} D_{st}\lambda_{st}. \qquad (16)$$

III. MANIPULATION PROCEDURE

Figure 1 shows the architecture of our proposed methodology. First, we investigate and formulate the problem under consideration. Second, we construct a two-layer index system that includes four first-level indexes and twelve second-level

TABLE 3. Values of random average consistency indexes.

	1	2	3	4	5	6	7	8	9
η_{ri}	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46

index, as shown in Table 3. The decision can be deemed if $\eta_{cr} < 0.1$ and the judgement is inconsistent if $\eta_{cr} \geq 0.1$.

Step 2: Normalization of evaluation results

To eliminate the influence of different magnitudes and units on decision results, a normalization formula is used to transform $x'_{st,ij}$ to $x_{st,ij}$, defined as follows:

$$x_{st,ij} = \frac{x'_{st,ij} - \min\limits_{s} x'_{st,ij}}{\max\limits_{s} x'_{st,ij} - \min\limits_{s} x'_{st,ij}} \quad (21)$$

Step 3: Calculation of IRCD

The IRCD in t^{th} year of the first-level index C_i for certain school a_s is calculated via equations (10)-(12).

Step 4: Calculation of time weight using maximal entropy method.

To calculate the time weight in t^{th} year of the related indexes, we establish an optimal problem as following, in which it may be solved based on the maximum entropy method.

$$\max \sum_{t=1}^{T} w_i \ln w_i \quad \text{s.t} \quad \begin{cases} \gamma = \sum_{i=1}^{n} \dfrac{p-k}{p-1} \quad w_t \\ \sum_{t=1}^{T} w_t = 1 \end{cases} \quad (22)$$

where the magnitude of γ means the importance of time sequence in viewpoints of decision makers. The usual values of γ are {0.1, 0.2, 0.3, 0.4, 0.5} which respectively represent extremely important, strongly important, obviously important, slightly important, and equally important in viewpoints of decision makers for all data in all periods of time. In this study, we choose the middle value of $\gamma = 0.3$.

Step 5: Calculation of final IRCD

The final IRCD for certain school a_s can be calculated by equations (13)-(16).

IV. CASE STUDY AND DISCUSSION

This section includes the school background, problems in school, and implementation of integral AHP.

A. BACKGROUND AND PROBLEMS IN SCHOOL

Our investigation data were obtained from four different universities, denoted by a_s, b_s, c_s, and d_s, in Fujian Province, China. For the sake of similar comparison bases for all cases, we only choose the engineering colleges from these schools, which are: the college of mechanical and electrical engineering in a_s school, the college of mechanical and car engineering in b_s school, the college of mechanical and automation engineering in c_s school, and college of mechanical and intelligence manufacturing in d_s school. These colleges had

TABLE 4. Index values of C_i for colleges of a_s, b_s, c_s, and d_s universities.

	2014				2015				2016				2017			
	a_s	b_s	c_s	d_s	a_s	b_s	c_s	d_s	a_s	b_s	c_s	d_s	a_s	b_s	c_s	d_s
C_1	1	0.5513	0.4282	0	1	0.7175	0.5085	0	1	0.4831	0.5372	0	1	0.3356	0.5145	0
C_2	0.1189	1	0.4098	0	0.5086	1	0.7457	0	0.4031	1	0.5814	0	0.5847	1	0.7238	0
C_3	0	0.2624	1	0.0099	0	0.1659	1	0.0654	0.1118	0.1992	1	0	0.131	0.1244	1	0
C_4	0.1892	1	0.4054	0	1	0.75	1	0	0	1	0.25	0.05	0.1111	1	0.8889	0
C_5	0.74	0	1	0.2228	1	0.5053	0.7368	0	1	0	1	0.3	0.8	0.3	1	0
C_6	0.8088	0	0.6765	1	1	0	0.0982	0.2321	0.2276	0.0407	0	1	0.5094	0	0.4151	1
C_7	0.0933	0.7902	1	0	0.1496	0.5384	1	0	0.2742	0.5581	1	0	0.3528	0.3699	1	0
C_8	1	0.5071	0.8105	0	1	0.5152	0.7926	0	1	0.5988	0.8253	0	1	0.6389	0.9751	0
C_9	0	1	1	1	0	0.6667	0.3333	1	0	0	1	1	0	0.3333	1	0.3333
C_{10}	1	0.0722	0.268	0	1	0.1653	0.281	0	1	0.2168	0.1888	0	1	0.1429	0.2286	0
C_{11}	1	0.3099	0.2254	0	1	0.2453	0.217	0	1	0.2174	0.1739	0	1	0.1812	0.1449	0
C_{12}	0.6	0.2	1	0	1	0.0909	0.7273	0	0.4	0.1	1	0	0.5882	0.1765	1	0

similar laboratory equipment allocations and financial investments in the recent years of 2014-2017.

B. IMPLEMENTATION OF AHP

First, we collect data of index values (C_i) for four different universities a_s, b_s, c_s, and d_s in years of 2014-2017, as shown in Table 4. These data are normalized via equation (21) and the calculation results are shown in Table 5.

Second, according to the survey by experts in conjunction with the results from calculation via equations (17)-(19), we obtain weights of the first-level W_{1i} and second-level indexes W_{2i}, as shown in Table 6. The consistency index is calculated via equation (20) and obtained as $\eta_{ci} = 0.059$. It is judged that the calculation result of weights satisfies the consistency requirement.

Third, based on previously obtained weights (listed in Table 6), we obtain the first-level indexes D_{sti} for four different colleges through calculation via equations (10) and (11). And the results are shown in Table 7. Then, we may construct an optimal evaluation weight problem as follows:

$$\max \quad -\{w_{2014} \ln w_{2014} + w_{2015} \ln w_{2015} + w_{2016} \ln w_{2016} + w_{2017} \ln w_{2017}\}$$

$$\text{s.t.} \quad \begin{cases} 0.3 = w_{2014} + \dfrac{2}{3} w_{2015} + \dfrac{1}{3} w_{2016}, \\ w_{2014} + w_{2015} + w_{2016} + w_{2017} = 1, \\ w_{2014} \geq 0.05, w_{2015} \geq 0.05, \\ w_{2016} \geq 0.05, w_{2017} \geq 0.05. \end{cases} \quad (23)$$

The above optimization problem is solved by using LINGO software, and the final synthetic weights are obtained as:

$$w_{2014} = 0.0984, w_{2015} = 0.1647, w_{2016} = 0.2756,$$
$$w_{2017} = 0.4614. \quad (24)$$

Eventually the final IRCD may be obtained via equation (16) as:

$$D_{a_s} = 0.3858, D_{b_s} = 0.2713, D_{c_s} = 0.3855, D_{d_s} = 0.1218. \quad (25)$$

TABLE 5. Normalized values of C_i for colleges of a_s, b_s, c_s, and d_s universities.

	2014				2015				2016				2017			
	a_s	b_s	c_s	d_s	a_s	b_s	c_s	d_s	a_s	b_s	c_s	d_s	a_s	b_s	c_s	d_s
C_1	1	0.5513	0.4282	0	1	0.7175	0.5085	0	1	0.4831	0.5372	0	1	0.3356	0.5145	0
C_2	0.1189	1	0.4098	0	0.5086	1	0.7457	0	0.4031	1	0.5814	0	0.5847	1	0.7238	0
C_3	0	0.2624	1	0.0099	0	0.1659	1	0.0654	0.1118	0.1992	1	0	0.131	0.1244	1	0
C_4	0.1892	1	0.4054	0	1	0.75	1	0	0	1	0.25	0.05	0.1111	1	0.8889	0
C_5	0.74	0	1	0.2228	1	0.5053	0.7368	0	1	0	1	0.3	0.8	0.3	1	0
C_6	0.8088	0	0.6765	1	1	0	0.0982	0.2321	0.2276	0.0407	0	1	0.5094	0	0.4151	1
C_7	0.0933	0.7902	1	0	0.1496	0.5384	1	0	0.2742	0.5581	1	0	0.3528	0.3699	1	0
C_8	1	0.5071	0.8105	0	1	0.5152	0.7926	0	1	0.5988	0.8253	0	1	0.6389	0.9751	0
C_9	0	1	1	1	0	0.6667	0.3333	1	0	0	1	1	0	0.3333	1	0.3333
C_{10}	1	0.0722	0.268	0	1	0.1653	0.281	0	1	0.2168	0.1888	0	1	0.1429	0.2286	0
C_{11}	1	0.3099	0.2254	0	1	0.2453	0.217	0	1	0.2174	0.1739	0	1	0.1812	0.1449	0
C_{12}	0.6	0.2	1	0	1	0.0909	0.7273	0	0.4	0.1	1	0	0.5882	0.1765	1	0

TABLE 6. Weights of the performance evaluation index system of LE assets.

First-level index	Weights W_{1i}	Second-level index	Weights W_{2i}
C_1	0.045	C_{11}	0.0035
		C_{12}	0.022
		C_{13}	0.020
C_2	0.285	C_{21}	0.185
		C_{22}	0.066
		C_{23}	0.034
C_3	0.236	C_{31}	0.018
		C_{32}	0.140
		C_{33}	0.078
C_4	0.434	C_{41}	0.034
		C_{42}	0.211
		C_{43}	0.189

TABLE 7. First-level indexes for four universities in different years.

Year	$D_{st}(a_s)$	$D_{st}(b_s)$	$D_{st}(c_s)$	$D_{st}(d_s)$
2014	0.5740	0.4887	0.6033	0.2678
2015	0.7321	0.4289	0.5881	0.2290
2016	0.5807	0.4188	0.5567	0.2733
2017	0.6403	0.4510	0.6527	0.1770

Apparently, it is deduced that

$$D_{a_s} > D_{c_s} > D_{b_s} > D_{d_s}, \qquad (26)$$

in which it means that the synthetic performance sequence for fixed asset of LE among schools a_s, b_s, c_s, and d_s in years of 2014-2017.

As can be seen from equation (25) that universities a_s and c_s have better usage performances than universities b_s and d_s for the asset allocation of laboratory equipment. Meanwhile,

it is seen from equation (26) that university a_s has the best performance for the asset allocation of laboratory equipment, while university d_s has the worst.

From the above in-depth investigation, we summarize that:

1) The reason of high performance score for university a_s is that it has obvious achievements in student cultivation than others. However, the final synthetic score of university a_s is only slightly greater than university c_s because of less financial investment in the laboratory equipment.

2) The university c_s has the highest financial investment in the laboratory equipment and meanwhile it has a better average performance index than other universities. However, owing to the apparently weak achievement of student cultivation, university c_s behaves a little bit worse than university a_s eventually.

3) Both universities b_s and d_s are insufficient for the financial investment of laboratory equipment. This results in worse asset-usage performances for universities b_s and d_s than for universities a_s and c_s. However, due to better behaviors in the equipment usage and benefit, the synthetic score of university b_s is higher than the university d_s.

4) From equation (16), we may obtain the differences between final IRCD (d_s) of universities a_s, b_s, c_s and d_s as 0.0003, 0.1142, 0.1495, respectively. It is seen that if the financial investment in laboratory equipment for university a_s increases, it will cause a great increase in synthetic score than that for university c_s. On the contrary, if the achievement of student cultivation for university c_s increases, it will cause a slight increase in synthetic score than that for university a_s.

C. CORRELATION ESTABLISHMENT USING GST

To quantitatively study the synthetic performance for the fixed asset of laboratory equipment among schools, we now
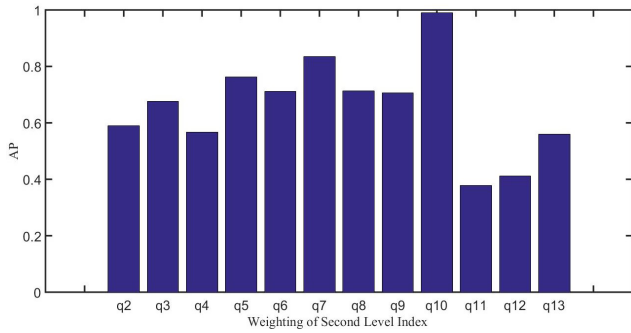
FIGURE 2. Influential weightings of $\hat{C}_i$ on *AP*.

introduce the GM(1,N) scheme whose details were mentioned before. Considering the data of second-level index values listed in Table 4, we first take averages of C_i in years 2014 to 2017, denoted as $\bar{C}_i$. Then $\bar{C}_i$ is normalized to $\hat{C}_i$ on the basis of their maximum values. A questionnaire survey, using second-level indexes $\hat{C}_1 \sim \hat{C}_{12}$ as independent variables and the performance of fixed asset of laboratory equipment (*AP*) as dependent variable, was done to thirty related professional employees of universities. The results of target *AP* was estimated in the form of semantic-differential method using credits with $1\sim7$ points. Further normalization of *AP* is carried out and it is found that the sequence of *AP* keeps the same as that in equation (26). However, this time we obtain a subjective and meaningful credits of *AP*.

In constructing the correlation between second-level indexes and *AP* using the GM(1,N) scheme, we set z_1 as *AP* and $z_2 \sim z_{13}$ as $\hat{C}_1 \sim \hat{C}_{12}$ in equation (4) and solve equations (5)~(9). A correlation result based on the a first-order ordinary-differential-equation is obtained and shown in Figure 2, where coefficients $q_2 \sim q_{13}$ mean the influential weightings of $\hat{C}_1 \sim \hat{C}_{12}$ on *AP*. Considering the top three, it is seen that $\hat{C}_9$, defined as the undamaged LE, has the largest influential weighting (q_{10}) on *AP*. And $\hat{C}_6$, defined as the fund rate of private enterprise, has the second influential weighting (q_7) on *AP*. And $\hat{C}_4$, defined as funded by school, has third influential weighting (q_5) on *AP*. If we increase $\hat{C}_9$, $\hat{C}_6$, and $\hat{C}_4$, it will cause an apparent increase in *AP*. Furthermore, the last three indexes: $\hat{C}_{12}$, $\hat{C}_{11}$, and $\hat{C}_{10}$ that have weightings q_{13}, q_{12}, and q_{11} respectively, have minor effects on *AP* comparing to other indexes. Investments on the last three terms are less effective. The influential sequences of all second-level indexes on *AP* can be expressed as

$$q_{10} > q_7 > q_5 > q_8 > q_6 > q_9 > q_3$$
$$> q_2 > q_4 > q_{13} > q_{12} > q_{11} \quad (27)$$

V. CONCLUSION

This study proposes a complete and structural asset index system as well as an integral data mining method which include the integral AHP and GST schemes to investigate the performance and find out the correlation for asset usage of laboratory equipment in universities. We use the hierarchy process (AHP) scheme in conjunction with the method of

relative closeness degree to globally evaluate the asset performance of different universities. And, the GM(1,N) of the grey system theory is used to locally investigate the correlation between second-level indexes and the final performance. The results of case study show that the university a_s has the best *AP* among all schools and the first three influential second-level indexes on *AP* are: $\hat{C}_9$ (undamaged LE), $\hat{C}_6$ (asset funded by private enterprise), and $\hat{C}_4$ (asset funded by school). The proposed methodology is an innovative and effective scheme to analyze the concerning issue of asset performance of laboratory equipment in universities both globally and locally.

REFERENCES

[1] H. Jacobs, S. Müller, and M. Weber, "How should individual investors diversify? An empirical evaluation of alternative asset allocation policies," *J. Financial Markets*, vol. 19, pp. 62–85, Jun. 2014.

[2] Y. Shi, W. Duan, L. Fleskens, M. Li, and J. Hao, "Study on evaluation of regional cultivated land quality based on resource-asset-capital attributes and its spatial mechanism," *Appl. Geography*, vol. 125, Dec. 2020, Art. no. 102284, doi: 10.1016/j.apgeog.2020.102284.

[3] Q. Shi and B. Li, "The evaluation and comparison of three benchmark asset pricing models with daily data: Supplementary evidence," *Asia–Pacific J. Accounting Econ.*, to be published, doi: 10.1080/16081625.2020.1787851.

[4] X. Xu, "A study on assessment method of on-performing loans in static-owned banks," Ph.D. dissertation, College Manage. Econ., Tianjin Univ., Tianjin, China, 2007.

[5] X. Han, H. Bui, S. Mandal, K. R. Pattipati, and D. L. Kleinman, "Optimization-based decision support software for a team-in-the-loop experiment: Asset package selection and planning," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 43, no. 2, pp. 237–251, Mar. 2013, doi: 10.1109/TSMCA.2012.2201467.

[6] H. Ge, J. Hou, and S. Asgarpoor, "Multiperspective risk analysis for aging asset fleet management," in *Proc. IEEE Power Energy Soc. Gen. Meeting*, Jul. 2012, pp. 22–26, doi: 10.1109/PESGM.2012.6345207.

[7] C. Corciova, D. Andritoi, and R. Ciorap, "Elements of risk assessment in medical equipment," in *Proc. 8th Int. Symp. Adv. TOPICS Electr. Eng. (ATEE)*, May 2013, pp. 23–25.

[8] A. N. Refenes and M. Azema-Barac, "Neural network applications in financial asset management," *Neural Comput. Appl.*, vol. 2, no. 1, pp. 13–39, Mar. 1994.

[9] Y. Hao, S. Huang, W. Liu, X. Chang, Y. Wu, Z. Liu, and Y. Geng, "A comprehensive evaluation method for asset management performance of distribution network based on optimal combination weight," in *Proc. China Int. Conf. Electr. Distrib. (CICED)*, Sep. 2018, pp. 17–19.

[10] Y. Shen, X. Peng, and T. Shi, "A grey comprehensive evaluation method of power quality based on optimal combination weight," *Autom. Electr. Power Syst.*, vol. 40, no. 18, pp. 76–83, 2016.

[11] D. Feng and J. Wu, "Value prediction methods based on neural network," *Comput. Eng.*, vol. 31, no. 6, pp. 160–162, 2005.

[12] S. Wei, J. Zhang, and Z. Li, "A supplier-selecting system using a neural network," in *Proc. IEEE Int. Conf. Intell. Process. Syst.*, Oct. 1997, pp. 468–471.

[13] F. Çebi and D. Bayraktar, "An integrated approach for supplier selection," *Logistics Inf. Manage.*, vol. 16, no. 6, pp. 395–400, Dec. 2003.

[14] C. K. Kwong, W. H. Ip, and J. W. K. Chan, "Combining scoring method and fuzzy expert systems approach to supplier assessment: A case study," *Integr. Manuf. Syst.*, vol. 13, no. 7, pp. 512–519, Nov. 2002.

[15] L. Davis and G. Williams, "Evaluating and selecting simulation software using the analytic hierarchy process," *Integr. Manuf. Syst.*, vol. 5, no. 1, pp. 23–32, Mar. 1994.

[16] A. Sarfaraz, P. Mukerjee, and K. Jenab, "Using fuzzy analytical hierarchy process (AHP) to evaluate Web development platform," *Manage. Sci. Lett.*, vol. 2, no. 1, pp. 253–262, Jan. 2012.

[17] T. L. Satty, *The Analytic Hierarchy Process*. New York, NY, USA: McGraw-Hill, 1980.

[18] D. Ju-Long, "Control problems of grey systems," *Syst. Control Lett.*, vol. 1, no. 5, pp. 288–294, Mar. 1982.

[19] J. L. Deng, "Introduction to grey system," *J. Grey Syst.*, vol. 1, no. 1, pp. 1–24, 1989.

JI HUI was born in Yinchuan, China, in 1975. She received the B.S. degree in information-based education management from Ningxia University, Yinchuan, in 1998, and the M.S. degree in software engineering from the Huazhong University of Science and Technology, Wuhan, in 2013. From 1998 to 2010, she worked with the Second Northwest Institute for Nationalities. Since 2013, she has been an Assistant Researcher and worked with the Assets Management Department, Sanming University. She is the author of ten articles. Her research interests include data statistics, data mining, modeling, and prediction analysis, and application for assets management in universities.

KUN-CHIEH WANG was born in Taichung, Taiwan, in 1963. He received the M.S. degree in mechanical engineering from National Tsing Hua University, Taiwan, in 1986, and the Ph.D. degree in mechanical engineering from National Taiwan University, Taiwan, in 1988.

From 2003 to 2012, he was an Associate Professor with the Department of Technological Product Design, College of Design, Ling Tung University, Taiwan. From 2012 to 2018, he was a Professor with the Department of Industrial Design, College of Information and Design, Overseas Chinese University, Taiwan. Since 2019, he has been a Professor with the School of Mechanical and Electronic Engineering, Sanming University, China. He owns over 70 international and domestic inventions (patents). He has published over 40 SCI or EI articles. His research interests include data mining, artificial intelligence, thermal error compensation of machine tools, computer-aided analysis, and Kansei engineering.

• • •