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Analysis of University Science Research Capability Elements and Evaluation based on BP Neural Network

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ABSTRACT

After analyzing effect elements of University Science Research Capability (USRC) based on dynamic capability theory, combined the substance of university science research with the highly self-organized, self-adapted and self-learned characteristics of Back Propagation (BP) Neural Network, the paper conducts a research on evaluation of USRC, in which an evaluation index system of USRC is constructed and a 15-7-1-typed BP Neural Network with three layers is presented to evaluate USRC, which provides a BP Neural Network-based methodology for evaluation of USRC with multiple inputs.

Keywords: *BP neural network, science research, capability evaluation*

1. Introduction

The capability of a university decides its competitive advantage and management performance in the essence [1]. Therefore, it does make sense for universities to accumulate, develop, evaluate and utilize their capabilities.

Nowadays, science research capacity is the core of universities and an important indication of any powerful university, all the universities tend to pay attention to cultivate and enhance their capabilities, especially science research capability. It's necessary to analyze and evaluate science research capability elements of universities. A number of researches have already been conducted on evaluating competitive capabilities [2,3,4,5,6]. However, few researches have been taken on evaluating scientific research capacity in universities. To fill in this gap, the paper, first, investigates into the elements of university science research capability based on dynamic capability, and then, constructs BP Neural Network model of evaluation, in the end, introduces into a simulation evaluation, aiming at providing both theoretical and empirical perspectives in the cultivation of university science research capability.

2. Analysis of USRC Based on the Theory of Dynamic Capability

2.1. The Theory of Dynamic Capability

The theory of dynamic capability is proposed firstly by Teece, Pisano and Shuen in "Firm Capability, Resource and Strategic concept" [7]. The theory of dynamic capability develops and consummate gradually in "Dynamic Capabilities and Strategic Management" by Teece, Pis-

ano and Shuen [8]. They defined dynamic capability as the capability of conforming, constructing and reconfiguring inner and exterior capabilities to adapt environment changed rapidly. The definition has two outline: "dynamic" namely, enterprises must renovate capabilities of themselves to adapt changeful environment; "capability" namely, strategic management has key function in renovating capabilities of themselves to adapt changeful environment. Some scholars consider that capability can be defined as the gather of enterprise knowledge and capability that can change capability is technology knowledge [9].

2.2. Analysis of USRC Based on Characteristics of Dynamic Capability

The theory of dynamic capability comes from the theory of resource base and absorbs many viewpoints of the theory of core capability, thus, its characteristic is similar with the theory of core capability, for example, the nature of value, the nature of unique. Nevertheless, dynamic capability is the capability that changes capabilities; its difference in nature from core capability is that it's the nature of deploitation [10]. Since science research activities of universities can't depart from resource base, the products of universities science research activities has the value of applying and generalizing, science research characteristics of each universities are different from others and different from the advantage of science research competition rest with the nature of unique. Universities should renovate constantly their science research capa-

bilities for adapting the changes of environment and keeping the advantage of competition.

The theory of dynamic capability is production of conforming inside knowledge and absorbing outside knowledge [11]. Absorbing knowledge has bridge function in resource and capabilities between inside and outside, thus, the theory of dynamic capability emphasizes to construct special capabilities of absorbing knowledge from outside. Universities must enhance learning intercourse between internal and overseas to heighten science research capabilities. Universities can absorb advanced knowledge from outside and master international learning development trends. Universities should increase the opportunity of studying abroad and visiting, besides, should introduce into visiting professors. The communion of experiences is good for importing advanced techniques and methods.

2.3. Analysis of University Science Research Capability Effect Elements

Competitive advantages of universities come from science research capability. The elements of university science research capability can be elaborated from four aspects: science research input, transformation efficiency and science research output and science research management. Combined with the features of university development, science research capability can be classified into four aspects, i.e., science research input capability, transformation efficiency capability and science research output capability and science research management, science research input capability effect university science research capability, science research output capability reflect university science research capability and transformation efficiency capability effect university science research capability indirectly, a sound management mechanism makes effect elements exert supreme efficiency and makes the whole benefit exceed the summation of parts. Science research management is holistic macroscopically elements of effecting USRC, as shown in Figure 1.

Science research input capability and science research output capability affect each other in science research process. Science research input capability provides substance base and intellect sustainment for science research output capability. Science research output capability act on science research input capability and provides reliable basis for science research input capability. Transformation efficiency capability is used for transforming between science research input and science research output effectively.

3. Comparison and Selection of Evaluation Methods

As to the evaluation of USRC, such methods as Analytic Hierarchy Process (AHP), Fuzzy Comprehensive Evaluation (FCE) and Data Envelopment Analysis (DEA) have been adopted with certain effects [12,13,14].

3.1. Analytic Hierarchy Process (AHP)

AHP is proposed by American T. L. Satty in 1970s [15], its essential principle is that setting down evaluation scheme on the basis of objects with gradual rank, sub-objects, restriction condition and adopting the method of comparing between one and the other to make sure judgment matrix, and then, making proportion vectors of characteristic vector that maximum characteristic of judgment matrix corresponding to as coefficient, in the end, presenting the power weight of each schemes synthetically. The method is an improvement of the method of adding power average, however, when evaluation scale is very large and there are too many evaluation indexes, the method prefer appearing problems, for example, judgment matrix is difficult with meeting the requirement of conformity. USRC there are too many evaluation indexes, therefore, it can result with the difficulty in meeting the requirement of conformity by AHP.

3.2. Fuzzy Comprehensive Evaluation (FCE)

Fuzzy Comprehensive Evaluation (FCE) is proposed by Peizhuang Wang [16]. It has two steps: individual evaluation according to each factor; integrative evaluation
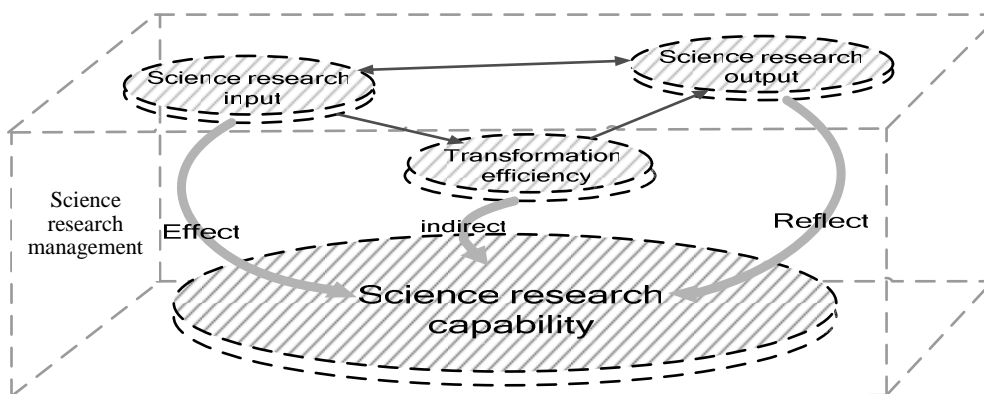

Figure 1. University scientific research capability elements system

according to all the factors. Its primary function is that quantificational evaluation to qualitative indexes. However, it has two shortages: firstly, it's difficult to compartmentalize the criterion of evaluation, for example: the limit between "very good" and "good" is difficult to ascertain, there are no specific criterions; secondly, the quality of expert mark can't be ensured. Because of intense subjectivity, FCE can't be used for evaluating USRC.

3.3. Data Envelopment Analysis (DEA)

DEA is a systems analysis evaluation method established on the basis of relative efficiency evaluation concept and given by A. Charnes and W. W. Cooper [17]. It supposes there are n decision making units (DMU), every DMU has m kinds of input and s kinds of output. When evaluating USRC, determinate selection rule should be transformed into data envelopment analysis model. Firstly, compartmentalize selection rule as input variable and output variable, and then, establish data envelopment analysis model and calculate relative efficiency of every university, in the end, the place of USRC can be obtained on the basis of calculation results. However, the method has relative validity because of being constructed on the basis of comparing each other. The evaluation of USRC isn't only used for getting horizontal comparison of many universities, but also getting vertical dynamic development trends. Because of disadvantages of DEA in relativity, the evaluation of USRC can't adopt DEA.

3.4. BP Neural Network

Among these methods, DEA is limited to the evaluation of ascertained performance indexes, AHP has restrict of evaluation scales, while FCE shows subjectivity in such aspects as data collection and index weight determination. Meantime, all these methods are based on the assumption of linear relations between indexes and can only be adopted within limits.

Characterized as self-adaptability, self-learning and large-scale parallel calculation ability, BP Neural Network is the most commonly used network model [18] in such aspects as identification, classification, evaluation, forecast, nonlinear mapping and simulating complex system [19]. BP Neural Network is a multiple-layer feedback network featured in back propagation of errors and constituted of input, hidden and output layers.

BP Neural Network is the simplification, abstraction and simulation of brain function. And it is a highly sophisticated and nonlinear dynamic system, in which nonlinear mapping is adopted to find out inner relations according to the existing training-set and through learning and training. Without the process of subjective calculation of index weight, the evaluation model proposed in the paper decreases the subjectivity and overcomes the possible linear problem between indexes effectively, which enhances the reliability and adaptability of evaluation for USRC.

4. Establishment of USRC Evaluation Model Based on BP Neural Network

4.1. Establishment of the Index System of USRC Evaluation

Competitive advantages of universities come from science research capability. A sound evaluation index system is the basis of effective evaluation of USRC. According to the establishment principles of index system [20] and based on many interrelated reference literatures [21,22,23,24], this paper selects science research input capability, transformation efficiency capability and science research input capability as the First-order indexes and further proposes the index system to evaluate synthetically USRC, as shown in Table 1.

Table 1. Evaluation index system of USRC

Object Layer	First-order indexes	Second-order indexes
		Science research expense (U_1)
	Science research input capability	Science research procession (U_2)
		Subject and science research base (U_3)
		Science research equipment and condition (U_4)
		Personnel opening degree (U_5)
	Transformation efficiency capability	Learning intercommunion (U_6)
		The amount of project (U_7)
USRC		Cooperation capability(U_8)
		Science research production (U_9)
	Science research output capability	Production application (U_{10})
		Student cultivation (U_{11})
		Project finishing status (U_{12})
		Science research input management capability(U_{13})
	Science research management capability	Transformation efficiency management capability(U_{14})
		Science research output management capability(U_{15})

4.2. Pre-treatment of evaluation index data

Evaluation index system consists of quantitative and qualitative indexes. Quantitative indexes can be further divided into positive, reverse and moderate indexes [25]. Considering the difficulties in comprehensive evaluation directly based on the data and the convergence problem of BP Neural Network, normalized and trend-assimilated pre-treatment is needed first. For qualitative indexes, we can make sure them by the method evaluation grade subjection degree, for example, 1, 0.75, 0.5, 0.25, 0 correspond respectively very good, good, common, bad, and very bad. For quantitative indexes, there are three steps:

(1) Calculate the average value $\overline{P_j}$ of the jth test index P_j,

$$\overline{P_j} = \frac{(\sum_{i=1}^{n} x_{ij})}{n}, j = 1, 2, k, m \qquad (1)$$

(2) Calculate middle variable of index M_{ij}:

If bigger target values indicate better effects, i.e. benefit index,

$$M_{ij} = \frac{x_{ij} - \overline{P_j}}{\left| \overline{P_j} \right|} \qquad (2)$$

If smaller target values indicate better effects, i.e. cost index,

$$M_{ij} = \frac{p_j - x_{ij}}{\left| \overline{P_j} \right|} \qquad (3)$$

If fixed scope values indicate better effects, i.e. scope index,

when

$$x_{ij} \leq A, \ M_{ij} = \frac{x_{ij} - A}{|A|} \qquad (4)$$

when

$$x_{ij} \geq B, \ M_{ij} = \frac{B - x_{ij}}{|B|} \qquad (5)$$

when

$$B \geq x_{ij} \geq A, \quad M_{ij} = 6 \qquad (6)$$

In Function (4), (5) and (6), A and B are best top boundary and best bottom boundary of scope indexes, M_{ij} reflects the degree x_{ij} deflects to average.

Calculate subjection degree function value Y_{ij} of indexes transforming to [-1, 1]

$$Y = \frac{1 - e^{-M_{ij}}}{1 + e^{-M_{ij}}} \qquad (7)$$

4.3. Design of Physical Structure of USRC Evaluation Model

The selection of network model structure is very important. Good selection can reduce the network training times and raise the network learning precision. The selection procedure includes:

(1) Ascertain the layer number of BP Neural Network. Theorem A. H. Kolmogrov has proven that a nonlinear neural network with three layers and S-typed action function will approach any continuous function with any precision as long as it possesses enough hidden nodes [26]. As a result, the paper adopts three-layer BP Neural Network in constructing the evaluation model of USRC, as shown in Figure 2. As to the function between nodes, S (Sigmoid)-typed function is introduced, as shown in Function (8).

$$f(x) = \frac{1}{1 + e^{-x}} \qquad (8)$$

(2) Ascertain the numbers of neural cell nodes both in the input layer and output layer of BP Neural Network. The numbers are dependent on outer description. The node number in the input layer is the number of characteristic factors (independent variable) while that in the output layer is the number of targets in the system. As a result, we can conclude that the input-layer node number is 15 and the output-layer is one, according to the index system of USRC evaluation as shown in Table 1.

(3) Ascertain the node number in the hidden layer of BP Neural Network. The node number in the hidden layer has a direct relation with the requirements and the node numbers both in the input and output layers. Too few nodes will result in the failure in network training or in the identification of unseen set before, while, too many ones will result in an excessively long learning period and an unobvious reduction in errors. Therefore, an optimal node number must be existent. Up to the present, no sound method has been found to ascertain the number. On the basis of previous researches on BP Neural
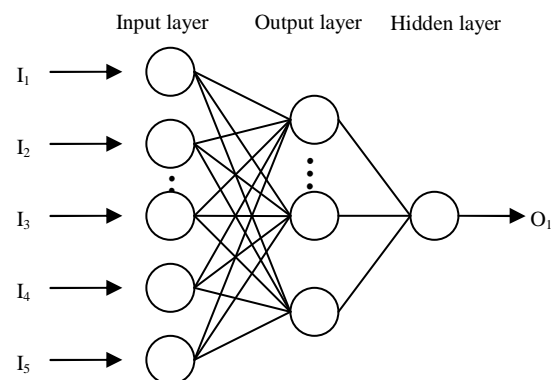

Figure 2. BP Neural network model structure

Network, two empirical formulas are concluded as follows:

$$\lambda = \sqrt{0.12m^2 + 0.43mn + 0.77m + 2.54n + 0.35} + 0.51 \quad (9)$$

$$\lambda = \sqrt{m + n} + A \quad (10)$$

In Function (9) and (10), m indicates the node number in the input layer, while n that in the output layer. A indicates any integer between one to ten. λ is the ascertained node number in the hidden layer.

According to Function (9) and (10) and the effectiveness of models, the node number in the hidden layer is assumed seven.

4.4. The Selection of Logic Algorithm in the Evaluation Model of USRC

The BP algorithm put forward by Rumelhart provides neural network with a more practical and effective training method. However, the algorithm has limitations when applied in complex systems for the high nonlinearity results in the low efficiency and slow convergence of the initial BP algorithm. In order to overcome these obstacles, the paper adopts a refined algorithm, a combination of additional momentum and Adaptive Learning Rate Method.

According to the BP Algorithm and the Minimum Mean-square Error, we can conclude the connection weight adjusting function of additional momentum factors:

$$\Delta w_{ij}(k+1) = (1-\alpha)\eta\delta_i x_j + \alpha\Delta w_{ij}(k) \quad (11)$$

$$\Delta b_i(k+1) = (1-\alpha)\eta\delta_i + \alpha\Delta b_i(k) \quad (12)$$

In Function (11) and (12), k indicates the training number. Δw_{ij} and Δb_i indicate the increments of weight. η indicates the learning rate. δ_i is error. x_j is network input. α is momentum factor and the average value is 0.9.

The value of η decides the success of algorithm to some extent. Large value results in the oscillation of error function and small value the slowness of convergence. In order to solve this, the method of adapting learning rate is adopted in the network training, i. e. Adaptive Learning Rate Method and the adapted function is concluded as follows [27]:

$$\eta(k+1) = \begin{cases} 1.05\eta(k), erf(k+1) < erf(k) \\ 0.7\eta(k), erf(k+1) > 1.04erf(k) \\ \eta(k), else \end{cases} \quad (13)$$

$$erf = \sum_{i=1}^{N}(T_i - O_i)^2 \quad (14)$$

In Function (13) and (14), erf is the error function. T_i is the expected output value of learning set. O_i is the real output value of learning set. N is the number of learning sets.

5. Empirical Research of Model

According to the evaluation index system above, the paper selects 12 groups of samples and divides into two parts. The former 8 groups are adopted in network training as learning sets and the latter 4 groups in network test. Besides, the paper selects 15 second-order inputting indexes and adopts the module of artificial neural network in MATLAB software. After the learning process of the evaluation of USRC, the BP Neural Network-based evaluation model of USRC is concluded. This process consists of the following steps:

(1) Select 12 groups of evaluation indexes as learning sets. The input values are the attribute values of 15 indexes after pre-treatment and the corresponding output value expected is the evaluated value of each sample.

(2) Start up the learning process after the normalization of index attributes and iterate the process till convergence. In this process, the network toolbox of MATLAB7.0 is used, with a learning rate of 0.01, a momentum factor of 0.9, a maximum training step of 2000 and an error precision of 0.0001. During the training, some obviously abnormal data have been eliminated through the displaying function of variance chart in MATLAB and the learning results have been achieved, as shown in Table 2.

(3) Restore the trained parameters of the BP Neural Network with three layers into the corresponding knowledge database and input respectively 4 groups of validating data to further examine the network model. The comprehensive examination result is comparatively ideal, which validates the effectiveness of the model, as shown in Table 3.

The simulation evaluation result with test samples is the same as experts' evaluation result basically. The application example indicates that the network has comprehensive practicability. The model can master expert knowledge by sample learning and be used evaluation with many indexes.

Table 2. The results of learning

Sample code	Training value	Expected value	Relative error (%)
1	0.556	0.549	1.28
2	0.117	0.119	-1.68
3	0.547	0.551	-0.73
4	0.423	0.421	0.48
5	0.113	0.116	-2.59
6	0.368	0.365	0.82
7	0.649	0.651	-0.31
8	0.235	0.227	3.52

Table 3. The examination results

Sample code	Training value	Expected value	Relative error (%)	Simulation place	Expert place
9	0.225	0.227	-0.88	4	4
10	0.345	0.343	0.58	3	3
11	0.435	0.433	-0.46	2	2
12	0.556	0.555	0.18	1	1

6. Conclusions

This paper constructs an evaluation index system of USRC combined with characteristics of universities based on dynamic capability theory, after analyzing effect elements of USRC, the paper presents a 15-7 -1-typed BP Neural Network with three layers to evaluate USRC on the basis of the highly self-organized, self-adapted and self-learned BP Neural Network comprehensive evaluation method. The method constructs a comprehensive evaluation model combined with both quantitative and qualitative indexes which is close to human being thought mode better. The satisfying result is obtained by emulational test. Its advantages embodies in the following aspects: avoiding the effects of subjectivity and randomicity in traditional evaluating methods and ensure the preciseness and objectivity of results; according with the empirical situation along with the increasing number of training samples; and overcoming the possible linear problems among the indexes and enhancing the reliability and adaptablity of evaluation. Therefore, compared with the traditional evaluating methods of USRC, the one based on BP Neural Network is of better practicability. BP Neural Network can learn by random sample parameter and construct diverse evaluation model. It can get reliable evaluation result on the basis of practical test sample after learning successfully; meanwhile analysis result will be accurate and factual when training samples increase gradually, therefore, the method has more comprehensive applicability.

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