Research on the Sustained Development Evaluation System of Horizontal Scientific Research Projects in Colleges and Universities based on BP neural network

Lina Gui[1,a], Jianan Lin[2,b*]

{87815149@qq.com[a], adingna@163.com[b*]}

Office of Science & Research, Chengyi College, Jimei University, Xiamen, China[1]
Department of Information Engineering, Chengyi College, Jimei University, Xiamen, China[2]

Abstract. Horizontal scientific research projects in colleges and universities play an important role in promoting innovation-driven development, advancing the integration of industry, academia, and research, nurturing talents, and driving economic development and enhancing social influence. However, to ensure the sustainable development of these projects, it is necessary to establish an effective evaluation system. This study adopts the AHP-BP neural network method to research the sustainable development evaluation system of horizontal scientific research projects in colleges and universities. Through this evaluation system, key influencing factors in project development can be identified, and the actual development of horizontal scientific research projects in the incubation and implementation phases can be effectively assessed. The research findings can provide effective support for the incubation and implementation of horizontal scientific research projects in colleges and universities, further promoting their sustainable development and enhancing their contribution to innovation and socio-economic development.

Keywords: Scientific Research Projects; the Three Circle Theory; AHP analysis method; BP neural network

1 Introduction

Horizontal research projects in universities refer to research projects conducted jointly by universities and external partners such as enterprises, government agencies, etc.[1] These projects are different from the teaching and basic research of the university and usually aim to solve practical problems, meet market demands, or promote industrial development. Horizontal research projects in universities can involve multiple disciplines such as engineering, natural sciences, social sciences, etc., and have certain financial support. These projects play an important role in promoting innovation, nurturing talents, promoting the integration of industry, academia, and research, as well as driving economic development.

By collaborating with external institutions such as enterprises and government agencies to carry out technological innovation, universities can transform research findings into practical applications, meet market demands, and drive the development of the economy and society. At the same time, it provides a platform for innovation and entrepreneurship for teachers and students, cultivates innovative thinking and practical abilities, and enhances their competitiveness in employment. Successful implementation of horizontal research projects not

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only solves practical problems but also has significant social impact, improving environmental quality, providing medical services, etc., making positive contributions to social development. Therefore, universities should attach importance to and actively participate in horizontal research projects to maximize the transformation of scientific and technological achievements and social value.

The importance of establishing an evaluation system for the continuous development of horizontal research projects in universities lies in providing scientific, comprehensive, and objective evaluation methods to effectively measure and improve the quality and effectiveness of these projects. By establishing an evaluation system, comprehensive assessments can be made on the innovation, implementation effects, and economic value of the projects, providing scientific basis for decision-makers to guide rational allocation of resources and management decisions. Additionally, the evaluation system also helps identify problems and challenges in the projects, promoting the transformation of technological achievements and industrial development through continuous optimization and improvement. By establishing a sound evaluation system, not only can the management level and efficiency of horizontal research projects in universities be improved, but it can also promote cooperation and communication between universities and external institutions such as enterprises and government agencies, driving technological innovation and sustainable development of the economy and society. Therefore, the construction of an evaluation system for the continuous development of horizontal research projects in universities has significant meaning and value.[2]

2 The construction of an evaluation system for the continuous development of horizontal research projects based on the "Three Circle Theory"

2.1 Basic Principles

The "Three Circle Theory" refers to a theoretical framework for the transfer and commercialization of scientific and technological achievements in universities. This theory was primarily proposed by American scholars David B. Audretsch and Maryann P. Feldman. The theory divides the process of technological innovation into three stages: the basic research circle, the applied research circle, and the commercialization circle, emphasizing the connections and interactions between these stages.[3][4]

The basic research circle refers to the pure scientific research conducted by universities and other research institutions, aiming to promote knowledge discovery and theory establishment. Research in this stage often lacks clear commercial objectives but provides an important scientific foundation for subsequent applied research.

The applied research circle involves applying the findings of basic research to solve practical problems and drive technological innovation. Universities can collaborate with enterprises, government agencies, and others to transform the results of basic research into practical technology solutions or product prototypes, which are then validated and improved. This stage emphasizes the feasibility and practicality of technological achievements, providing substantial preparation for subsequent commercialization.

The commercialization circle involves promoting the commercialization and industrial development of the applied research outcomes. In this stage, universities can establish partnerships with companies to facilitate technology transfer, product development, and market promotion. Through the commercialization circle, technological achievements can truly meet market demands, create economic value, and foster industrial development.

The "Three Circle Theory" emphasizes the close connections and interactions between basic research, applied research, and commercialization. It presents a pathway and methods for universities to transfer and commercialize their scientific and technological achievements from the laboratory to the market. By integrating these three circles effectively, universities can better achieve the transfer and commercialization of technological achievements, driving their contribution to the economy and society through technological innovation.

The "Three Circle Theory" can be used to evaluate the continuous development of horizontal research projects because it provides a comprehensive framework that identifies and measures the key elements of the technological innovation pathway. The interrelationship between the basic research circle, applied research circle, and commercialization circle reflects the process of technological achievements from theory to practical application and then to commercialization. By evaluating these three circles, we can identify strengths, areas for improvement at different stages of the project, and whether scientific rigor, feasibility, and commercial value have been adequately considered. Considering these factors holistically enables a more accurate assessment of the continuous development of horizontal research projects and provides valuable guidance for their optimization and decision-making. Therefore, the "Three Circle Theory" offers a comprehensive and effective approach to evaluate the continuous development of horizontal research projects.

2.2 Building an evaluation system for the continuous development of horizontal research projects

A systematic analysis of the influencing factors on the sustained development of horizontal research projects in universities, combined with literature research, will be conducted. The core points will include "the value of the project itself," "the capabilities of the project implementers," and "external support elements for project development." This analysis will examine the overall incubation status of horizontal research projects in universities and the factors that affect their actual development process. Ten experts and scholars from relevant fields will be invited to use the Delphi method[5] to select indicators and clarify key influencing factors. This will establish an evaluation system for the sustained development of horizontal research projects, which includes three primary indicators and twenty-nine secondary indicators, as shown in Figure 1.

In this evaluation system, the value of the project will mainly be assessed based on its economic and social benefits. The project team's capabilities will be evaluated comprehensively based on research abilities, marketing abilities, innovation abilities, and team-building situations. External environmental support for the project will be assessed by considering four aspects: government-industry-academia-research. This assessment will focus on technical guidance, market environment, funding support, communication, and exchange, providing a comprehensive evaluation of the external conditions required for project development. The entire evaluation system closely connects the horizontal research project itself, the project team, universities, governments, and enterprises. It enables an objective, three-dimensional, and integrated evaluation of the current status of sustained development of horizontal research projects. Subsequently, the AHP-BP neural network method will be used to calculate and verify the weights of the indicators, ultimately creating an evaluation system that accurately reflects the current status of project development and the key factors for sustained development.

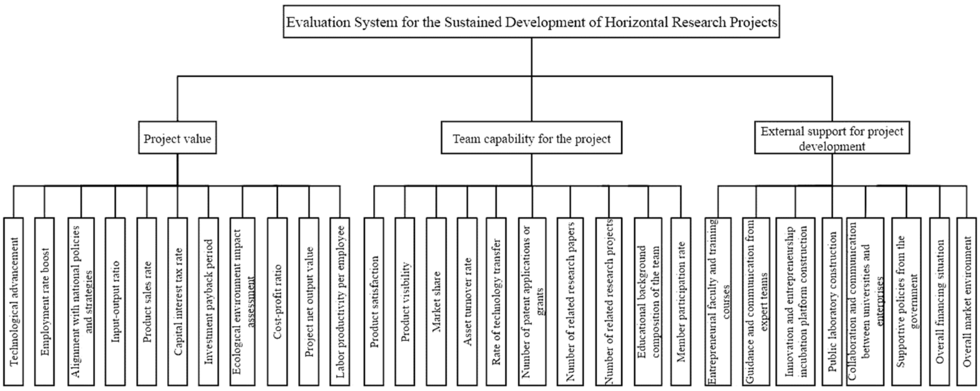

Fig. 1. Evaluation System for the Sustained Development of Horizontal Research Projects

3 Based on the AHP, the weight calculation of the evaluation system

This chapter focuses on the empirical analysis of the continuous development evaluation system of horizontal scientific research projects in colleges and universities, using the specific case of Chengyi College at Jimei University as an example.

3.1 Data source

The data for this study is compiled from various levels of horizontal research projects from the School of Chengyi at Xiamen University from 2015 to 2023. A total of 100 research projects have been collected (as shown in Table 1, only a partial display due to the large number). Among them, there are 2 projects in 2015, 1 project in 2016, 3 projects in 2017, 4 projects in 2018, 10 projects in 2019, 12 projects in 2020, 24 projects in 2021, 19 projects in 2022, and 25 projects in 2023.

Table 1. College Horizontal Research Projects and Funding Overview

No.	Year	Project Name	Total Amount
1	2017	Demonstration Project of Unmanned Aerial Photography for Xixi River in Yongding County	53,888.00
2	2018	Research on the Development of Xiamen Port by Leveraging Land Ports to Expand Economic Hinterland	35,000.00
3	2018	Compilation of "Chinese Water Transport History" and "Records of Chinese Water Transport Engineering Construction" (Zhangzhou Section)	98,000.00
4	2018	Research on the Interactive New Form of Contemporary Chinese Film and Television Dramas with Novels	50,000.00

5	2018	Research and Development of Equipment for CO2 and SO2F2 Mixed Fumigation Based on Three Waste Quarantine Treatment	45,000.00
6	2019	Research and Development of Traditional Intangible Cultural Heritage Handicraft Courses	100,000.00
7	2019	Safe Navigation Security Plan for Deep Structural Land-Sea Measurement of Fujian and Taiwan Straits	20,000.00
8	2019	Research on the Construction of Practical Course System for Early Childhood Education - Taking Chengyi College as an Example	15,000.00
9	2019	Research on Early Development and Education of Infants Aged 0-3	30,000.00
10	2019	Current Status and Suggestions for the Commercial Format Development of Zhongshan Road, Xiamen	10,000.00
11	2019	Analysis of Tax Burden and Planning Strategies in the Retail Industry	10,000.00
12	2019	Development of Security Engineering Drawings Recognition for Chongqing Jiangjin District Xueliang Project Design based on Hand-drawn Sketches	135,000.00
13	2019	Declaration Plan for Xiamen Port-type National Logistics Hub	140,000.00
14	2019	Legal Advisory Services on Maritime and Commercial Cases involving Navigation and Cargo Transportation Technology	160,000.00
15	2019	Research and Development of Remote Control Dynamic Multi-parameter Gas Safety Assessment Robot	24,000.00
16	2019	Market Research Services for Respiratory Ventilators and Related Products	31,000.00
17	2019	Construction of Industry-Education Integration Financial Laboratory	40,000.00
18	2020	Fine-grained Information Intelligence Service for Tokyo Olympic Games Swimming Events Preparation	95,000.00
19	2020	Feasibility Study Report on Points-based Universal (Exchangeable) Shopping Mall Platform System	10,000.00
20	2020	Development of Comprehensive Personnel Management System for Dormitory Buildings	200,000.00
21	2020	Protection and Development Planning for Old and Well-known Brands in Xiamen	50,000.00
22	2020	Co-building of a Base for the Volunteer Alliance in Promoting Law and Innovating Legal Publicity and Education	200,000.00
23	2020	Research and Development of Cultural and Creative Model Design for Shouning Wooden Arch Bridge	46,000.00
24	2020	Research on Teacher Skill Enhancement and Industry Development in the Education and Training Industry	100,000.00
25	2020	Research on the Construction of Credit System for College Students (Phase 1)	200,000.00
26	2020	Report on the Development of Private Economy in Siming District (2018-2019)	20,000.00
27	2020	Requirements Analysis for Product Marketing Space Management System of a Large-scale Food Company	100,000.00
28	2020	Research and Development of High-speed Vision Counting System	300,000.00
29	2021	Online Course Development for "Children's Games and Guidance"	35,000.00
30	2021	Digital Course Design and Development Services	50,000.00

3.2 Evaluation System Indicator Weight Calculation

A total of 38 experts and scholars from 16 universities and research institutions, including Jimei University and Jimei University Chengyi College, were invited. Their research fields cover disciplines such as ideological and political education, innovation and entrepreneurship management, enterprise project incubation, finance, and investment. An expert group was formed.

The evaluation system was constructed using the YAAHP software to build an indicator model. Based on this, an expert scoring table and a survey questionnaire for subsequent indicator optimization were designed. The experts quantitatively scored the indicators using the 1-9 scale method. The geometric mean of each expert's scores was calculated to test the consistency of the judgment matrix. During the consistency testing process, adjustments and revisions were made to the judgment matrix multiple times until the overall consistency test C.R. of the hierarchy was less than 0.1, meeting the requirement for consistency of the judgment matrix.

After the consistency test, the YAAHP software was used to calculate the weights of the evaluation system indicators, as shown in Table 2 and Figure 2. In the first-level indicators, the weight of project value is 0.6186, which is the highest, while the weight of external support for project development is 0.1277, which is the lowest. In the second-level indicators, key indicators include the alignment of the project with national policies and strategies, project input-output ratio, project funding interest tax rate, project-related technology conversion rate, project team patent applications or ownership, project market share, and government policy support.

In this indicator system, feedback data from continuous research was randomly sampled and compiled into a sample set for training and testing of the BP neural network, providing data support for subsequent optimization of indicator system weights.

Table 2. Evaluation System Indicator Weights

Primary Indicator	Symbol	Weight Coefficient	Secondary Indicator	Symbol	Weight Coefficient
Project value	B1	0.6186	Technological advancement	C11	0.0070
			Employment rate boost	C12	0.0688
			Alignment with national policies and strategies	C13	0.1010
			Input-output ratio	C14	0.1211
			Product sales rate	C15	0.0168
			Capital interest tax rate	C16	0.0737
			Investment payback period	C17	0.0609
			Ecological environment impact assessment level	C18	0.0015
			Cost-profit ratio	C19	0.0437
			Project net output value	C110	0.0210
			Labor productivity per employee	C111	0.1030
Team capability	B2	0.2537	Product satisfaction	C21	0.0176

for the project			Product visibility	C22	0.0298
			Market share	C23	0.0093
			Asset turnover rate	C24	0.0340
			Rate of technology transfer	C25	0.0148
			Number of patent applications or grants	C26	0.0369
			Number of related research papers	C27	0.0389
			Number of related research projects	C28	0.0422
			Educational background composition of the team	C29	0.0254
			Member participation rate	C210	0.0047
External support for project development	B3	0.1277	Entrepreneurial faculty and training courses	C31	0.0070
			Guidance and communication from expert teams	C32	0.0279
			Innovation and entrepreneurship incubation platform construction	C33	0.0047
			Public laboratory construction	C34	0.0253
			Collaboration and communication between universities and enterprises	C35	0.0165
			Supportive policies from the government	C36	0.0305
			Overall financing situation	C37	0.0024
			Overall market environment	C38	0.0135

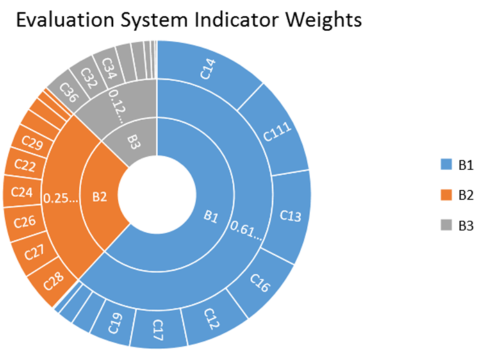

Fig. 2. Evaluation System Indicator Weights

4 Based on BP neural network verification

4.1 Basic Principles

The BP neural network algorithm consists of three processes: BP neural network design, learning training, and testing verification. It is one of the widely used optimization algorithms currently. It is based on the feedback working principle of the human brain. During the forward propagation of signals, errors are gradually transmitted backward layer by layer. Through repeated learning training on training samples, the errors are reduced in the direction of the gradient, thus continuously adjusting the weights and thresholds between layers to achieve the required target accuracy in the output results.[6]

4.2 Constructing the BP neural network model

When setting the network structure, we can use the weights determined by the Analytic Hierarchy Process (AHP) for the evaluation system of ongoing research projects as input variables. The optimized results of the indicator system can be used as a single output value. Based on empirical formulas and multiple random experiments, we can select the number of nodes in the hidden layer as m=7. We can also choose the tansigS activation function for the transformation from the input layer to the output layer of the BP neural network. For the transformation from the hidden layer to the output layer, we can use the purelin linear function. With these selections, we can construct a three-layer (input layer, hidden layer, and output layer) BP neural network model in MATLAB for subsequent neural network learning and testing.

4.3 Training and testing of the BP neural network

A comprehensive survey lasting for half a month was conducted through questionnaires to various groups related to the horizontal research projects in the Chengyi College of Jimei University from 2015 to 2023. The participants were asked to rate the indicator factors in the evaluation system according to their importance using a scoring rule on a scale of 0 to 100. The data was then normalized and transformed into a range of [0,10]. A total of 108 responses were obtained from the survey. After filtering out invalid and incomplete data, 98 valid data points were included in the database.

For the training of the BP neural network, a random sampling method was used to select 78 data points from the database as the training samples. The remaining 20 data points were reserved as the testing sample set to evaluate the performance of the network. The results after the learning training and testing are shown in Table 3.

Table 3. Results of BP Neural Network Learning and Testing

Sample ID	Expected Output	Predicted Output	Relative Error (%)
1	7.19248	7.19827	-0.08047%
2	6.62102	6.63809	-0.25779%
3	6.20000	6.19632	0.05936%
4	6.90023	6.92326	-0.33373%
5	6.75016	6.74892	0.01839%

6	6.78489	6.80779	-0.33758%
7	7.04388	7.05845	-0.20674%
8	7.20000	7.20179	-0.02486%
9	6.54171	6.53619	0.08450%
10	6.95187	6.98038	-0.41000%
11	6.62102	6.60844	0.19000%
12	6.87725	6.87166	0.08130%
13	6.80011	6.80848	-0.12306%
14	7.19248	7.20392	-0.15909%
15	6.38495	6.39462	-0.15136%
16	6.80011	6.81716	-0.25069%
17	6.46911	6.47607	-0.10770%
18	6.54171	6.54865	-0.10610%
19	7.19248	7.18450	0.11095%
20	6.20000	6.19412	0.09483%

In the testing samples, there is a high degree of overlap between the expected values and the actual values. The maximum relative error is 0.41%, which falls within an acceptable range. This indicates that the network's output results are relatively reliable.

After training the network using the training data, we obtained a training performance curve. It was observed that the training could be completed after 5 iterations. At this point, the accuracy of the network reached 8.691×10^{-21}, which meets our desired precision requirement (less than 10^{-20}). The accuracy of the BP neural network is commonly measured using error metrics, such as Mean Squared Error (MSE). Figure 3 shows the training performance curve of the BP neural network.

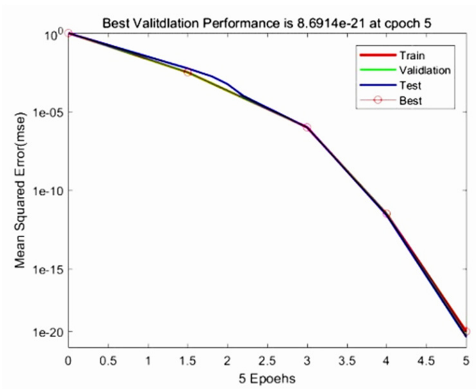

Fig. 3. The training performance of the BP neural network

Meanwhile, the root mean square error (RMSE) of the calculation results is 0.011443, the mean squared error (MSE) is 0.00013095, the mean absolute error (MAE) is 0.0090095, the average relative percentage error is 0.11475%, and the coefficient of determination (R2) is 0.99986. The predicted results for each sample data are shown in Figure 3, where the R value for the training samples is 0.9999, for the validation samples is 0.99986, for the testing samples is 0.99989, and for the overall samples is 0.99989. All these R values are close to 1, indicating high accuracy of the model's predictions. Therefore, the neural network simulation results are reliable, and the weights of the evaluation system obtained through the AHP hierarchical analysis method are reasonable and effective. In Figure 4, all the R values are approximately equal to 1, demonstrating a very good fit of the data and a high level of prediction accuracy.

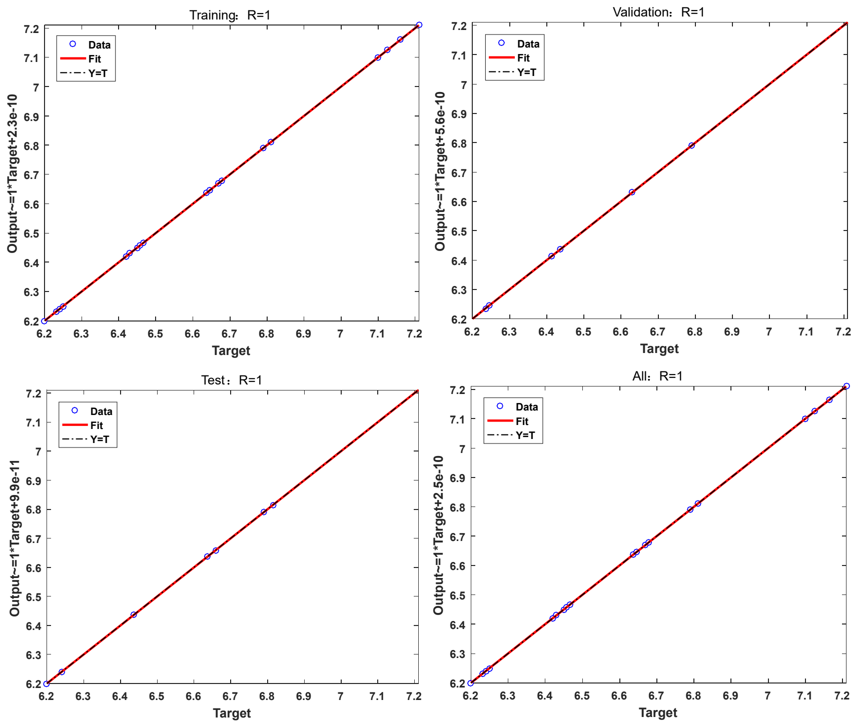

Fig. 4. BP neural network data fitting results

5 Conclusion

In the era of innovation-driven development, it is imperative to continuously deepen the reform of the innovation and entrepreneurship education system. This entails fostering stronger collaboration among government entities, industries, academia, research institutions, and businesses. The primary objective is to enhance the conversion rate of innovation and entrepreneurship achievements, foster greater integration between science and technology and the economy, and establish a powerful engine for economic growth in this new era. It is crucial to establish a paradigm where innovation not only fuels entrepreneurship but also drives employment opportunities.

To accomplish these goals, it is essential to streamline the development process of entrepreneurial projects, from the initial stages of pre-research to their successful implementation. Identifying key factors for project incubation and implementation is vital, as it allows for focused efforts on nurturing and supporting projects to thrive. Moreover, the establishment of an objective and comprehensive evaluation indicator system becomes pivotal. This system facilitates an accurate assessment of the current state of horizontal scientific research projects. Consequently, it enables the formulation of targeted support systems specifically designed to aid in the development of such projects. These endeavors hold immense value and significance by fostering the incubation, long-term transformation, and realization of the full potential of horizontal scientific research projects within university settings.

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