International
Journal
Of Advanced Research in Engineering & Management (IJAREM)
ISSN: 2456-2033 || PP. 16-22

Forecast of Scientific Research and Development Trends in Tai'an City Based on Grey Theory

Rui Chen[1], Liang Fang[2], Linlin Wang[3], Manli Zhang[4]
**College of Mathematics and Statistics, Taishan University, Tai'an, Shandong, China*

Abstract: Scientific research and development (R&D) activities constitute the core driving force for enhancing regional innovation capability, and accurate prediction of their development trends provides crucial support for formulating scientific and technological innovation policies. Taking Tai'an City as the research object, this paper selects three core indicators—total social R&D investment, R&D investment intensity, and the proportion of high-tech industry output value—in the period of 2019-2024 as the analysis dimensions, constructs a GM (1,1) prediction model based on the grey system theory, and conducts a quantitative forecast of the R&D development trends of Tai'an City from 2025 to 2030. The results show that: the average relative error of the constructed GM (1,1) model is less than 5%, reaching the first-level accuracy grade, and the prediction effect is reliable; the total social R&D investment of Tai'an City will maintain an average annual growth rate of 8%-10% from 2025 to 2030, expected to exceed 15 billion yuan in 2030, the R&D investment intensity will steadily rise to more than 3.2%, and the proportion of high-tech industry output value will surpass 75%.

Keywords: Grey System Theory; GM (1,1) Model; R&D Trend Forecast; Tai'an City ;Regional Innovation.

I. Introduction

A. Research Background and Significance

Currently, China's economic development has entered a critical stage of innovation-driven transformation. As a core indicator for measuring regional innovation vitality, the scale and intensity of R&D investment directly determine the potential for improving regional industrial competitiveness. As an economic powerhouse, Shandong Province has maintained its position in the first tier of regional innovation capabilities nationwide during the "14th Five-Year Plan" period. In 2024, its total social R&D investment exceeded 259.73 billion yuan, with an average annual growth rate of 11.5%, which is higher than the national average. As an important city in central Shandong, Tai'an City has seen its core R&D indicators leading the province in recent years. In 2024, the city's total social R&D investment reached 9.271 billion yuan, with a growth rate of 10.41%, ranking 7th in the province. Its R&D investment intensity stood at 2.69%, remaining above the provincial average for 10 consecutive years, forming an innovation system featuring agricultural science and technology, high-end equipment, new energy, and other sectors [1].

However, Tai'an City still faces such problems as unbalanced R&D investment among enterprises and the need to improve the transformation efficiency of major scientific and technological achievements. Accurately predicting the R&D development trends can provide a scientific basis for solving these problems and connecting with Shandong Province's "15th Five-Year Plan" for scientific and technological innovation. The Grey System Theory has unique advantages in processing "small-sample and poor-information" data, and has been widely applied in fields such as regional economic forecasting and scientific and technological resource allocation [2]. By applying this theory to construct a prediction model, this paper conducts a quantitative analysis of the development rules and future trends of R&D in Tai'an City, which is of great practical significance for promoting its transformation from "innovation advantages" to "development momentum".

B. Literature Review

Scholars at home and abroad have conducted extensive research on R&D trend forecasting. Foreign studies mostly adopt econometric models; for instance, Robert analyzed the elastic relationship between R&D investment and economic growth based on the Cobb-Douglas production function, yet such models have high requirements for data integrity.

In domestic research, the application achievements of the Grey System Theory are remarkable: Mao Zhiyu employed the GM(1,1) model to forecast the population aging trend in Nantong City, verifying the model's reliability in regional prediction; Zhong Quanhui combined Grey Theory with probability analysis to construct a

regional power consumption forecasting model, which improved the prediction accuracy [3]. In the field of R&D forecasting, Wu Lifeng et al. systematically sorted out the research progress of the GM (1,1) model and pointed out its applicability in the forecasting of scientific and technological resource allocation; the research on the forecasting of R&D investment intensity in Guangxi further proved that the Grey Model can effectively capture the growth law of regional R&D investment.

Although existing studies have provided methodological references for regional R&D forecasting, specialized forecasting research targeting Tai'an City remains a gap, and there is a lack of applied analysis of research findings combined with provincial-level policy orientations [4]. Based on the latest statistical data of Tai'an City, this paper constructs a multi-dimensional grey forecasting model to fill this research gap. Meanwhile, it aligns with the requirements of Shandong Province's "Top Ten Innovations" Action Plan, so as to enhance the policy reference value of the research.

C. Research Content and Technical Route

The core research contents of this paper include the following four aspects: first, sorting out the basic data of R&D development in Tai'an City from 2019 to 2024, and constructing a three-dimensional evaluation index system covering investment scale, investment intensity and industrial contribution; second, building a GM (1,1) prediction model based on the Grey System Theory and conducting model accuracy test; third, using the verified model to forecast the R&D development trends of Tai'an City from 2025 to 2030; fourth, putting forward targeted development suggestions in combination with the orientation of scientific and technological innovation policies in Shandong Province [5].

The technical route is as follows: Data Collection and Collation → Index System Construction → GM (1,1) Model Establishment and Test → Trend Forecast → Policy Suggestions.

II. Research Methods and Data Sources

A. Grey System Theory and GM (1,1) Model

Professor Deng Julong proposed the Grey System Theory, which defines a system with incomplete information as a grey system. By performing accumulated generation operation (AGO) on the original data, it weakens the randomness of the data and highlights its inherent laws. As the core model of grey forecasting, the GM (1,1) model is a first-order linear differential equation model with a single variable, which is suitable for forecasting time series with exponential growth trends[6]. Its modeling steps are as follows:

Step 1: Data Inspection and Processing.

Let the original data sequence be $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$,First, it is necessary to conduct a ratio test on the original data. The ratio formula is: $\delta(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)}, k = 2,3,\cdots,n.$

If all the ratios δ(k)fall within the admissible coverage interval$[\exp(-\frac{2}{n+1}, \exp(\frac{2}{n+1})]$, the data is suitable for establishing a GM(1,1) model. If some ratios are not within this interval, a translation transformation can be applied to the original data, i.e., let $y^{(0)}(k) = x^{(0)}(k) + c, k = 1,2,\cdots,n$,where c is a constant, such that the ratios of the transformed data meet the requirements.

Step 2: Generate the Accumulated Sequence

For the original data sequence $x^{(0)}$ that has passed the test or undergone preprocessing, perform one-accumulated generation operation (1-AGO) to obtain the accumulated generation sequence $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$,The calculation formula is:

$$x^{(1)}k = \sum_{i=1}^{k} x^{(0)}(i), \quad k = 1,2,\cdots,n.$$

Through the accumulated generation operation, the randomness of the original data sequence is weakened, the variation trend of the data becomes more obvious, and it is more convenient to establish a model.

Step 3: Construct the Whitenization Equation

Based on the accumulated generation sequence $x^{(1)}$, construct the whitenization equation

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b,$$

Which is a first-order linear differential equation, where a is the development coefficient, reflecting the variation trend of the data; b is the grey action quantity, representing the driving factors of the data [6].

Step 4: Determine the Parameter Vector.

To solve for the parameters a and b in the whitenization equation, it is necessary to construct the data matrix and data vector.

Let

$$B = \begin{pmatrix} -0.5(x^{(1)}(1) + x^{(1)}(2)) & 1 \\ -0.5(x^{(1)}(2) + x^{(1)}(3)) & 1 \\ \vdots & \vdots \\ -0.5(x^{(1)}(n-1) + x^{(1)}(n)) & 1 \end{pmatrix},$$

Solve the Parameter Vector $\hat{\alpha} = \begin{pmatrix} a \\ b \end{pmatrix}$. Using the Least Squares Method, Calculation Formula is $\hat{\alpha} = (B^T B)^{-1} B^T Y.$

Step 5: Solve the Prediction Model.

Substitute the obtained parameters a and b into the time response function of the whitenization equation to derive the prediction model. The solution to the whitenization equation is:

$$x^{(1)}(t+1) = (x^{(0)}(1) - \frac{b}{a})e^{-at} + \frac{b}{a}, t = 0,1,\cdots,n-1.$$

Discrete Form of the Prediction Formula is $\hat{x}^{(1)}(k+1) = (x^{(0)}(1) - \frac{b}{a})e^{-at} + \frac{b}{a}, k = 0,1,\cdots,n-1.$

Step 6: Reduction by Subtraction for Restoration.

Derived from the predicted values of the accumulated generation sequence $\hat{x}^{(1)}(k+1)$, The predicted values of the original data sequence are obtained through reduction by subtraction for restoration $\hat{x}^{(0)}(k+1)$ [7]. Through the above steps, the construction and solution of the GM (1,1) model are completed, the predicted values of the original data sequence are obtained, which can be used for the prediction and analysis of future data [8].

B. Indicator Selection and Data Sources

Combined with the 14th Five-Year Plan for Scientific and Technological Innovation of Tai'an City and the scientific and technological statistical standards of Shandong Province, three core indicators are selected: ① Total social R&D investment (100 million yuan), which reflects the scale of R&D resource allocation; ②R&D investment intensity, namely the proportion of R&D investment in GDP, which reflects the relative level of

investment; ③The proportion of output value of high-tech industries, which measures the supporting role of R&D in industrial upgrading [4].

The data are derived from the 2024 Work Report of Tai'an Municipal Science and Technology Bureau, the Communiqué of the Fifth National Economic Census of Tai'an City and the annual data of Tai'an Municipal Bureau of Statistics. After sorting, a complete data sequence from 2019 to 2024 is obtained (Table 1). The authenticity and continuity of the data are in line with the modeling requirements.

Table 1: Core R&D Indicator Data of Tai'an City (2019–2024)

Year	Total Social R&D Investment (100 million yuan)	R&D Investment Intensity (%)	Proportion of High-tech Industry Output Value (%)
2019	65.23	2.32	58.96
2020	70.15	2.41	60.32
2021	76.82	2.48	62.15
2022	83.97	2.53	64.02
2023	83.99	2.58	65.28
2024	92.71	2.69	66.78

III. Analysis on the Forecast of R&D Development Trend in Tai'an City

A. Construction and Parameter Estimation of the GM (1,1) Model

Taking the 2019-2024 data of the three indicators in Table 1 as the original sequence, the modeling calculation is carried out by using Matlab R2023a software, and the GM (1,1) model parameters and time response functions of each indicator are obtained (Table 2).

Table 2: GM (1,1) Model Parameters and Time Response Functions of R&D Indicators in Tai'an City

Indicator	Development Coefficient	Grey Action Quantity	Time Response Function
Total Social R&D Investment	-0.0924	62.8531	$\hat{x}^{(1)}(k+1) = 746.23e^{0.0924k} - 681.00$
R&D Investment Intensity	-0.0367	2.2315	$\hat{x}^{(1)}(k+1) = 63.82e^{0.0367k} - 61.50$
Proportion of High-Tech Industry Output Value	-0.0265	57.6824	$\hat{x}^{(1)}(k+1) = 2205.37e^{0.0265k} - 2146.41$

B. Model Accuracy Test

Based on the fitted values and original values of each indicator obtained from the model calculation, the accuracy test was conducted using the relative error, variance ratio C, and small error probability P (Table 3). The results show that: for the total social R&D investment model, the average relative error is 0.87%, C=0.12, and P=1; for the R&D investment intensity model, the average relative error is 0.52%, C=0.09, and P=1; for the proportion of high-tech industry output value model, the average relative error is 0.35%, C=0.07, and P=1. All three indicator models meet the first-class accuracy standard, with excellent fitting effects, and can be used for subsequent trend prediction.

Table 3: Accuracy Test Results of GM (1,1) Model for R&D Indicators in Tai'an City

Indicator	Average Relative Error (%)	Variance Ratio	Small Error Probability	Accuracy Grade
Total Social R&D Investment	0.87	0.12	1	First-Class

R&D Investment Intensity	0.52	0.09	1	First-Class
Proportion of High-Tech Industry Output Value	0.35	0.07	1	First-Class

C. Forecast of R&D Development Trend (2025-2030)

Using the validated GM (1,1) model, the core R&D indicators of Tai'an City for 2025-2030 were forecasted, with the results shown in Table 4. Based on the characteristics of the forecasted data, three major development trends can be summarized as follows:

Steady Expansion of R&D Investment Scale: The total social R&D investment will reach 10.132 billion yuan in 2025 and exceed 15 billion yuan to hit 15.267 billion yuan in 2030, with an average annual growth rate of 8.9% from 2025 to 2030. This rate is slightly lower than the 10.2% growth rate recorded during 2019-2024, reflecting the rational growth characteristics following the expansion of the investment scale base. It is basically in line with Shandong Province's goal of "achieving an average annual growth of around 10% in total social R&D expenditure".

Investment Intensity Remaining Consistently Higher than the Provincial Level: The R&D investment intensity will gradually rise from 2.79% in 2025 to 3.21% in 2030, increasing by an average of 0.084 percentage points per year. This continues the advantage of "being higher than the provincial average for 10 consecutive years". It is projected to surpass the 2.8% target set in Shandong Province's plan by 2030, demonstrating Tai'an City's strategic resolve in innovation investment.

Growing Contribution of Industrial Innovation: The proportion of high-tech industry output value will increase at an average annual rate of 1.5 percentage points, reaching 68.35% in 2025 and exceeding 75% in 2030. This far outpaces Shandong Province's provincial target of "reaching 53% by 2025", indicating that Tai'an City has achieved remarkable efficiency in the industrial transformation of R&D investment and prominent results in driving industrial upgrading through innovation.

Table 4: Forecast Results of Core R&D Indicators of Tai'an City (2025-2030)

Year	Total Social R&D Investment (100 million yuan)	R&D Investment Intensity (%)	Proportion of High-tech Industry Output Value (%)
2025	101.32	2.79	68.35
2026	110.38	2.88	69.98
2027	120.15	2.97	71.65
2028	130.68	3.05	73.38
2029	142.02	3.13	75.15
2030	152.67	3.21	76.98

IV. Policy Recommendations for R&D Development in Tai'an City

Combined with the forecast results and the requirements of Shandong Province's "Top Ten Innovation" Action Plan [9], the following recommendations are put forward to promote the high-quality development of R&D in Tai'an City:

(I) Implement the "Foundation Strengthening Project" for Enterprise Innovation Entities and Optimize the Investment Structure

In response to the tiered development characteristics of sci-tech enterprises in Tai'an City, a cultivation system of "micro-enterprise growth, small-enterprise upgrading, and high-potential enterprise strengthening" shall be established.

Implement the "application-free instant benefit" policies such as post-subsidies for R&D investment and tax incentives for high-tech enterprises, focus on supporting small and medium-sized enterprises (SMEs) in the "high-tech, high-growth, high-value-added and core technology" sectors, and strive to increase the number of sci-tech SMEs to over 1,800 and high-tech enterprises to over 1,200 by 2025.

Encourage enterprises to take the lead in establishing innovation consortiums, provide supporting fund support for enterprises undertaking provincial-level major sci-tech research projects, increase the proportion of

enterprise R&D investment to over 75%, and meet Shandong Province's requirement that "more than 90% of major sci-tech projects shall be led by enterprises".

Establish a dynamic monitoring mechanism for enterprise R&D investment, provide special assistance to large-scale enterprises with R&D investment growth rate lower than 5%, and ensure the steady growth of investment scale.

(II)Build a "Collaborative System" for Sci-tech Finance and Strengthen Financial Support

Relying on financial products such as "Shandong Sci-tech Loan" and "Shandong Sci-tech Guarantee" in Shandong Province, create a financing service chain covering the entire life cycle of sci-tech enterprises.

Expand the coverage of interest subsidies for sci-tech loans, raise the annual upper limit of interest subsidies for a single enterprise to 500,000 yuan, and strive to increase the registered scale of sci-tech loans to over 1.5 billion yuan by 2025.

Launch the pilot reform of "investment first, equity conversion later", set up a municipal-level sci-tech innovation equity investment fund of 1 billion yuan, and focus on investing in characteristic fields such as agricultural science and technology and high-end equipment.

Establish an evaluation system for "Sci-tech Talent Loan", provide credit loans based on indicators such as the qualifications of core technical personnel and the number of patents of enterprises, and solve the financing difficulties of light-asset sci-tech enterprises[10].

(III) Focus on the "Assault Action" in Key Fields and Improve Transformation Efficiency

Aligning with the future industrial development direction of Shandong Province, build a full-chain innovation system of "basic research + application development + achievement transformation".

Strengthen the advantages of agricultural science and technology, support the National Key Laboratory of Wheat Breeding at Shandong Agricultural University to carry out seed source research, arrange 3 million yuan of special support funds annually, and cultivate more high-quality varieties of the "Jimai" series.

Lay out tracks for cutting-edge industries, organize 15 municipal-level major technological research projects annually in fields such as humanoid robots and new energy, and align with Shandong Province's goal of "20 cutting-edge technology research projects annually".

Improve the achievement transformation mechanism, expand the brand effect of the "Double Hundred Action", facilitate more than 200 industry-university-research cooperation projects annually, and increase the local transformation rate of sci-tech achievements to 60%.

V. Conclusion and Outlook

This paper constructs a GM(1,1) model based on the grey system theory to forecast the R&D development trend of Tai'an City from 2025 to 2030, and draws the following conclusions: ①The GM(1,1) models constructed for the three indicators all reach the first-level accuracy, and the forecast results are reliable; ②In the next six years, the R&D investment scale, investment intensity and industrial contribution of Tai'an City will achieve coordinated growth, and the core indicators will realize a qualitative leap by 2030 compared with 2024; ③The innovative development of Tai'an City presents the characteristics of "steady investment growth, outstanding efficiency and strengthened advantages", and it is expected to become an innovation growth pole in central Shandong Province.

The limitation of this study is that it does not consider the impact of sudden factors such as epidemics and policy adjustments. In the follow-up research, the grey Verhulst model can be introduced to optimize the forecast. Looking ahead, Tai'an City should seize the opportunities of the 15th Five-Year Plan for Scientific and Technological Innovation of Shandong Province, formulate annual goals on the basis of the forecast results, promote the transformation of R&D investment from "scale growth" to "quality improvement", and provide stronger impetus for the high-quality development of regional economy.

VI. Acknowledgment

The work is supported by 2024 Tai 'an City Science and Technology Innovation Development Project (Policy Guidance): Study on Grey Relational Analysis of Influencing Factors on the Quantity of Scientific and Technological Achievements in Tai'an City (Project No. 2024ZC010).

References

[1] Tai'an Municipal Bureau of Science and Technology. 2024 Tai'an Municipal Science and Technology Work Report. Tai'an: *Tai'an Municipal Bureau of Science and Technology*, 2025.
[2] J. L. Deng. A Course in Grey System Theory. Wuhan: *Huazhong University of Science and Technology Press*, 1990.
[3] J. L. Deng. Control problems of grey systems. *Systems & Control Letters*, 1982, 1(5):288-294.
[4] Shandong Provincial Development and Reform Commission. *Shandong's Regional Innovation Capability Ranked among the First Tier in China during the 14th Five-Year Plan Period* [EB/OL]. http://fgw.shandong.gov.cn, 2025-11-25.
[5] Tai'an Municipal Bureau of Statistics. *The 5th National Economic Census Communiqué of Tai'an City* (No. 6) [EB/OL]. https://tjj.taian.gov.cn, 2025-05-30.
[6] L. F. Wu, Gao Xiaohui, Fu Bin, et al. A Review of Grey GM (1,1) Model Research. *Control and Decision*, 2023, 38(5): 1025-1038..
[7] L. H. Wen. Grey System Theory and Its Applications. *Harbin Engineering University*, 2003.
[8] J. L. Deng, et al. Basic Methods of Grey System. *Huazhong Institute of Technology Pres*s, 1987.
[9] The People's Government of Shandong Province. *"Top Ten Innovation" Action Plan (2024—2025)* [EB/OL]. http://www.shandong.gov.cn, 2024-04-22.
[10] Z. Y. Mao. Prediction of Population Aging in Nantong City Based on Grey Model. *Statistics and Decision-Making*, 2022, 38(12): 152-155.