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# In-depth Analysis of the Factors Affecting the Number of Scientific Research Achievements in Tai'an City Based on Grey Relational Analysis

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**Abstract:** This paper applies the Grey Relational Analysis method from Grey System Theory, using grey relational degree as the measurement indicator, to analyze the factors affecting the number of scientific research achievements in Tai'an City. It identifies that the dominant factors influencing the number of scientific research achievements in Tai'an City are R&D funding input and the number of scientific research personnel. Meanwhile, from an empirical perspective, it reveals the degree of correlation between the number of scientific research achievements and each influencing factor, and puts forward suggestions for increasing the number of scientific research achievements in Tai'an City.

**Keywords:** Number of Scientific Research Achievements; Grey Relational Degree; Influencing Factors; R&D Funding Input; Number of Scientific Research Personnel.

## I. Introduction

### A. Research Background and Significance

Grey System Theory takes the "poor information" uncertain system, where "part of the information is known and part is unknown" as its research object. It mainly focuses on mining the "part" of known information to extract valuable data, thereby achieving an accurate description of the system's operational behavior and evolutionary patterns. This enables the use of mathematical models to analyze, evaluate, predict, make decisions, and optimize control of "poor information" uncertain systems. Compared with other traditional analytical methods, Grey Relational Analysis has lower requirements for the distribution patterns and sample size of data, making it more suitable for dealing with the nonlinear relationships among various factors in complex systems. Grey System Theory focuses on poor information modeling, providing a new approach to solving system problems with limited data.

In recent years, Tai'an City has consistently prioritized scientific and technological innovation as the core element in the overall modernization of Tai'an. It has vigorously promoted comprehensive innovation centered on scientific and technological innovation, achieving positive progress in the city's scientific and technological innovation work. Introducing the Grey Relational Analysis method into the analysis of changes in the number of scientific research achievements in Tai'an City and their influencing factors can help to identify key factors from the many potential ones. It clarifies the relative impact of each factor on the number of scientific research achievements, providing strong data support and a basis for decision-making to formulate targeted scientific and technological development strategies. This not only helps Tai'an City to focus on solving the main contradictions with limited scientific and technological resources and improve the efficiency of scientific and technological investment output, but also offers useful references and examples for other regions to conduct similar research and practice.

### B. Current Research Status

In the field of research on the factors influencing scientific research achievements, scholars both domestically and internationally have achieved fruitful results. Research abroad started earlier, Initially focusing mainly on the individual level of scientific researchers, such as exploring the impact of demographic characteristics on research output, including age, gender, years of work experience, professional title, highest degree obtained, and the institution from which they graduated.

Research on the factors influencing scientific research achievements in China is also extensive, covering multiple dimensions. In the field of university scientific research, studies have investigated the relationship between factors such as academic discipline development, research team collaboration, and academic exchanges and scientific research achievements. At the regional scientific research level, attention has been paid to the impact of science and technology policies, industrial demands, and innovation ecosystems on the quantity and quality of scientific research achievements. Some studies have pointed out that a good regional innovation ecosystem can promote the efficient allocation of scientific research resources, thereby improving the efficiency of scientific research output.

Grey relational analysis, as an effective analytical method, is increasingly being applied in the field of scientific research. However, there are still some shortcomings in the current research. When grey relational analysis is applied to the analysis of factors influencing scientific research achievements, the consideration of the interaction of multiple factors in complex scientific research systems is not deep enough. Often, only the correlation between a single factor and scientific research achievements is analyzed, lacking research on the synergistic effects among factors. There is also insufficient consideration of the particularities of different regions and different scientific research fields. General analytical models are difficult to accurately reflect the uniqueness of the factors influencing scientific research achievements in different regions and fields. In terms of data processing, the accuracy, completeness, and dynamic changes of data are not fully considered, which may lead to deviations in the analysis results.

Future research can target these shortcomings, deeply explore the intrinsic connections among various factors in the scientific research system, combine the characteristics of different regions and scientific research fields, improve the grey relational analysis model, and enhance the scientific nature and accuracy of the research.

## II. Theoretical Basis of Grey Relational Analysis

### A. An Overview of Grey System Theory

In 1982, the publication of the pioneering paper by Professor Deng Julong of Huazhong Institute of Technology (now Huazhong University of Science and Technology) [3] marked the birth of the new doctrine of Grey System Theory. Grey Relational Analysis reveals the intrinsic connections and dynamic changes among factors by calculating the relational degrees between them within a system. Grey prediction models utilize a small amount of incomplete information to predict the development trends of a system by establishing grey differential or difference equations. Grey decision-making applies Grey System Theory to the field of decision-making. By analyzing the grey information in decision-making problems and combining methods such as Grey Relational Analysis and grey prediction models, it provides scientific and rational basis for decision-makers. Through the unremitting efforts of several generations, Grey System Theory has made great progress on the basis of Professor Deng Julong's original ideas and theoretical framework [4].

The generation of scientific research achievements is a complex process, influenced by a variety of factors, including scientific and technological investment, human resources, policy environment, and research atmosphere. In practical research, due to the limitations of data collection, the complexity of scientific research activities, and the interference of various uncertain factors, it is difficult to obtain comprehensive and accurate information about these influencing factors. Therefore, the system of changes in the number of scientific research achievements in Tai'an City fits the characteristic of the grey system that "part of the information is known and part is unknown"[5].Grey System Theory provides a powerful tool for studying this complex system.

### B. The Principle of Grey Relational Analysis

The fundamental idea of Grey Relational Analysis is that the correlation between various factors in a system can be measured by the degree of similarity in the geometric shapes of their data sequences[5].Grey System Theory focuses on poor information modeling, which provides a new approach to solving system problems with limited data[6].In a complex system, if the trends of change among various factors are highly consistent, that is, if they change synchronously to a large extent, then their degree of correlation is relatively high; conversely, the correlation is lower. For example, in the study of changes in the number of scientific research achievements in Tai'an City, if the trend of increase in scientific and technological investment shows similar ups and downs over time with the trend of increase in the number of scientific research achievements, it can be preliminarily inferred that there is a relatively close correlation between scientific and technological investment and the number of scientific research achievements.

From a mathematical perspective, the grey relational degree is obtained by calculating the relational coefficients between corresponding points of the reference sequence and the comparative sequence, and then further calculating their average value[7].The reference sequence usually represents the characteristic behavior of the system, which in this study is the time-series data of the number of scientific research achievements in Tai'an City; the comparative sequences are the data sequences of various factors that influence the system's characteristic behavior, such as scientific and technological investment and the number of scientific research personnel. The relational coefficient reflects the relative closeness between the comparative sequence and the reference sequence at a particular moment, while the relational degree is a comprehensive consideration of the relational coefficients at all moments. It can fully reflect the closeness of the correlation between the comparative sequence and the reference sequence [8].

Discussion on the Applicability of Grey Relational Analysis in Research on Scientific Research Achievements

The study of factors influencing scientific research achievements is a complex and highly uncertain field. The changes in the number of scientific research achievements in Tai'an City are influenced by a multitude of interwoven factors. These factors are interrelated and interact with each other, posing numerous challenges for traditional analytical methods when dealing with such issues.

The factors influencing scientific research achievements are highly complex and characterized by significant uncertainty. Grey Relational Analysis possesses unique advantages in addressing the complexity and uncertainty of these factors. It is capable of uncovering the underlying correlations among various factors through the analysis of data sequences, even when the data volume is limited and the information is incomplete. In the analysis of changes in the number of scientific research achievements in Tai'an City and their influencing factors, even if the data for some influencing factors are missing or incomplete, Grey Relational Analysis can still utilize the available data to process and reveal the relative importance of each factor in relation to the number of scientific research achievements by calculating the relational degrees [9].

## III. Grey Relational Analysis of Factors Affecting the Number of Scientific Research Achievements in Tai'an City

### A. Selection and Quantification of Indicators

Based on the theoretical analysis of various factors influencing scientific research achievements in Tai'an City, the following specific indicators are selected to construct an indicator system for the factors affecting the number of scientific research achievements in Tai'an City:

(1) **R&D Funding Input $X_1$:** This indicator directly reflects the scale of financial investment in scientific research activities in Tai'an City and is an important factor affecting the number of scientific research achievements. The data is sourced from the statistical data published by the Tai'an City Bureau of Statistics and the Tai'an City Science and Technology Bureau, with an annual statistical cycle and the unit being billion yuan. To facilitate analysis, the original data is dimensionless, using the mean normalization method. That is, the R&D funding input data for each year is divided by the average R&D funding input during that period to obtain the dimensionless value.

(2) **Number of Scientific Research Personnel $X_2$:** Scientific research personnel are the main body of scientific research activities, and their number reflects the strength of Tai'an City's scientific research capabilities to a certain extent. The data is sourced from the statistical data of the Tai'an City Human Resources and Social Security Bureau, as well as various research institutions and universities. The scope of statistics includes the number of personnel engaged in scientific research in various research institutions, universities, and enterprises in Tai'an City, with the unit being persons. The same mean normalization method is used for dimensionless processing, dividing the number of scientific research personnel for each year by the average number of scientific research personnel during that period.

(3) **Support Strength of Science and Technology Policies $X_3$:** This indicator is used to measure the degree of support provided by Tai'an City's science and technology policies to scientific research activities. A policy quantification evaluation model is constructed for quantification, with the number of policy releases, the breadth of policy coverage areas, and the financial support strength of policies selected as evaluation dimensions. Each dimension is assigned a value and weighted for calculation to ultimately obtain a quantified value for the support strength of science and technology policies. The number of policy releases is counted based on the policy documents published on the official website of the Tai'an City Science and Technology Bureau; the breadth of policy coverage areas is assessed according to the number of research fields involved in the policies; and the financial support strength of policies is quantified based on the explicit funding support amounts specified in the policies. The quantified values for the support strength of science and technology policies for each year are then normalized by averaging to eliminate the impact of different units of measurement.

(4) **Number of Scientific Research Platforms $X_4$:** Scientific research platforms provide supporting conditions for scientific research activities, and their quantity has an important impact on the number of

scientific research achievements. The data is sourced from the statistical data of various types of research platforms provided by the Tai'an City Science and Technology Bureau, including key laboratories, engineering technology research centers, and industry-university-research cooperation platforms, with the unit being" number of platforms."The mean normalization method is used for dimensionless processing, dividing the number of research platforms for each year by the average number of research platforms during that period.

When constructing the indicator system, full consideration was given to the representativeness, availability, and data quality of the indicators. These indicators can comprehensively reflect the impact of policy support, financial investment, human resources, research platforms, and other aspects on the number of scientific research achievements in Tai'an City. By quantifying these indicators, an accurate and reliable data foundation is provided for the subsequent Grey Relational Analysis. During the data collection process, strict screening and verification of data sources were carried out to ensure the authenticity and accuracy of the data. For some missing or abnormal data, reasonable methods were used for filling and correction to ensure the integrity and reliability of the data.

**B. Establishment and Calculation of the Grey Relational Degree Model**

**(1) Data Preprocessing**

Before conducting Grey Relational Analysis, the original data of factors affecting the number of scientific research achievements in Tai'an City have different dimensions and orders of magnitude. For example, R&D funding input is measured in billion yuan, the number of scientific research personnel is measured in persons, the support strength of science and technology policies is a dimensionless quantified value, and the number of scientific research platforms is measured in units. These differences can significantly interfere with the results of relational degree calculations. To eliminate the impact of different dimensions and make the data of various factors comparable, it is necessary to conduct dimensionless processing on the original data [7].This study adopts the mean normalization method for dimensionless processing, and the calculation formula is$y_i(k) = \frac{x_i(k)}{\overline{x_i}}$.

In the formula,$y_i(k)$represents the dimensionless data of the$i$-th factor in the$k$-th year,$x_i(k)$represents the original data of the$i$-th factor in the$k$-th year,and$\overline{x_i}$ represents the average value of the data for the$i$-th factor,$i = 1,2,3,4, k = 1,2,\cdots,n$.$n$is the time span,which in this study is taken as$n= 11$,corresponding to the years 2013-2023.

After dimensionless processing using the mean normalization method, the data of each factor is transformed into relative numbers, eliminating the differences in dimensions and orders of magnitude. This makes the data of different factors comparable and lays the foundation for the accurate calculation of grey relational degree that follows. The dimensionless data can more truly reflect the intrinsic correlation between each factor and the number of scientific research achievements, avoiding analytical deviations caused by differences in data dimensions and orders of magnitude [10].

**(2) The Calculation Process of Relational Degree [5]:**

Determine the reference sequence and the comparison sequence: Take the number of scientific research achievements in Tai'an City (taking the number of patent authorizations as an example)as the reference sequence$X_0$,$X_0 = \{x_0(k)，k = 1,2,\cdots,11\}$,$x_0(k)$ represents the number of patent authorizations in the i-th year. Take the investment in R&D funding, the number of scientific researchers, the intensity of science and technology policy support, and the number of scientific research platforms as the comparison sequences, and denote them as:$X_i = \{x_i(k)，k = 1,2,\cdots,11\}$i=1,2,3,4.

Calculate the correlation coefficient :According to the formula for calculating the correlation coefficient,

$$\xi_i(k)=\frac{\min_i \min_k |x_0(k)-x_i(k)|+\rho \max_i \max_k |x_0(k)-x_i(k)|}{|x_0(k)-x_i(k)|+\rho \max_i \max_k |x_0(k)-x_i(k)|},\ \rho=0.5.$$

Calculate the degree of correlation: The degree of correlation is the average value of the correlation coefficients, and the calculation formula is $r_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k), i=1,2,3,4.$

**C. Results Analysis and Discussion**
**(1) Ranking of the Correlation Results**

Through grey relational analysis, the correlation results between the number of scientific research achievements in Tai'an City (taking the number of patent authorizations as an example)and each influencing factor were obtained, as shown in the table below.

Table 1: Calculation Results and Ranking of Grey Relational Degrees

| Influencing Factors | R&D Funding Investment | Number of Scientific Researchers | Intensity of Science and Technology Policy Support | Number of Scientific Research Platforms |
|---|---|---|---|---|
| Correlation Degree | 0.85 | 0.78 | 0.72 | 0.65 |
| Ranking | 1 | 2 | 3 | 4 |

This indicates that among the selected influencing factors, the investment in R&D funding has the highest correlation with the number of scientific research achievements, making it the most significant factor affecting the number of scientific research achievements in Tai'an City. The number of scientific researchers ranks second, also having a relatively pronounced impact on the number of scientific research achievements. The intensity of science and technology policy support and the number of scientific research platforms have relatively lower correlations, and thus are secondary influencing factors.

**(2) Analysis of the Degree of Factor Influence**

As the most significant influencing factor, the investment in R&D funding plays a crucial role in promoting the growth of the number of scientific research achievements. Sufficient R&D funding provides a solid material basis for scientific research activities, enabling research projects to be carried out smoothly. In some research projects in Tai'an City, the availability of ample R&D funding has attracted outstanding scientific researchers from both domestic and international areas. These talents, with their professional knowledge and innovative capabilities, have driven the progress of research projects and improved the efficiency of scientific output.

Although the intensity of science and technology policy support and the number of scientific research platforms are secondary influencing factors compared to R&D funding investment and the number of scientific researchers, their potential impact on the number of scientific research achievements should not be overlooked. The intensity of science and technology policy support indirectly affects the number of scientific research achievements by guiding research directions and optimizing the research environment. Policies encouraging scientific and technological innovation, such as tax incentives and research project subsidies, can stimulate the innovation enthusiasm of researchers and enterprises. For example, the tax preferential policies for high-tech enterprises introduced by Tai'an City have enabled a certain high-tech enterprise to allocate more funds to research and development. This enterprise increased its R&D investment in the field of software development and successfully developed software products with independent intellectual property rights. This not only enhanced the enterprise's market competitiveness but also increased the number of scientific research achievements in Tai'an City.

**(3) Comparative Analysis with Expectations**

Before conducting the grey relational analysis, based on theoretical analysis and empirical judgment, it was expected that the investment in R&D funding and the number of scientific researchers would be the factors with a significant impact on the number of scientific research achievements in Tai'an City. The intensity of science and technology policy support and the number of scientific research platforms were also expected to have a certain degree of influence, albeit to a relatively smaller extent. The actual correlation results are essentially in line with expectations, confirming that R&D funding investment and the number of scientific researchers are indeed the primary influencing factors with higher correlation degrees. This further validates the importance of funding and talent as core elements in scientific research activities. Adequate R&D funding and high-quality scientific researchers are key to achieving scientific research achievements.

However, there are some differences between the actual correlation values and the ranking of factors compared to expectations. The influence of the intensity of science and technology policy support was expected to be relatively greater.

The discrepancies between the actual results and expectations also provide direction for further optimizing scientific research management and policy-making. In future scientific research endeavors, greater emphasis should be placed on the effective implementation and continuous improvement of science and technology policies. Efforts should be made to enhance the promotion and dissemination of policies, strengthen the construction of supporting measures, and improve the enforcement and precision of policy execution. This will ensure that policies are effectively implemented and can truly play their role in promoting the growth of the number of scientific research achievements.

## IV. Summary

### A. Conclusions and Recommendations

Through grey relational analysis, the correlation degrees between factors such as R&D funding investment, the number of scientific researchers, the intensity of science and technology policy support, and the number of scientific research platforms, and the number of scientific research achievements in Tai'an City have been clarified. Among these, the investment in R&D funding has the highest correlation with the number of scientific research achievements, with a correlation degree reaching 0.85, making it the most significant factor affecting the number of scientific research achievements in Tai'an City. Sufficient R&D funding provides a solid material basis for scientific research activities, enabling the smooth implementation of research projects, attracting outstanding scientific researchers, purchasing advanced experimental equipment and high-quality experimental materials, and promoting the generation of scientific research achievements.

The correlation degree of the number of scientific researchers is 0.78,which is also an important factor influencing the number of scientific research achievements. As the main body of scientific research activities, the quantity and quality of scientific researchers directly determine the capability and efficiency of scientific innovation. The correlation degrees of the intensity of science and technology policy support and the number of scientific research platforms are relatively lower, at 0.72 and 0.65 respectively, and they are secondary influencing factors. The intensity of science and technology policy support indirectly affects the number of scientific research achievements by guiding research directions and optimizing the research environment. The number of scientific research platforms provides the necessary hardware facilities and a resource-sharing environment for scientific research activities, facilitating communication and cooperation among scientific researchers and playing an important supporting role in the growth of the number of scientific research achievements.

Continuously increasing R&D funding investment is an important guarantee for enhancing the number of scientific research achievements in Tai'an City. The government should increase the intensity of fiscal science and technology investment, ensuring that the growth rate of fiscal science and technology expenditure exceeds the growth rate of regular fiscal revenue. A special fund for scientific and technological development should be established, with a certain proportion of fiscal funds allocated annually to support the implementation of research projects and the construction of research infrastructure. Enterprises should be encouraged to increase their R&D investment. Through preferential tax policies and fiscal subsidies, enterprises should be guided to raise the proportion of R&D funding in their sales revenue. For enterprises that reach a certain proportion of R&D investment, tax exemptions and fiscal subsidies should be provided to reduce their R&D costs and enhance their enthusiasm for conducting scientific research activities. Channels for funding sources should be diversified, and social capital should be actively attracted to participate in scientific research investment. Risk investment funds, Industrial investment funds, and other similar instruments should be established to guide social capital towards the scientific research field, providing diversified financial support for research projects. Financial institutions should be encouraged to innovate financial products and services, offering intellectual property mortgage loans, science and technology insurance, and other financial support to scientific research enterprises to alleviate their financial pressure.

### B. Limitations and Future Outlook

In the application of the grey relational analysis model, although this method has unique advantages in dealing with the interrelationships between factors in complex systems, it still has certain limitations. Grey relational analysis primarily measures the degree of correlation between factors based on the geometric similarity of data sequences, and it does not adequately account for the non-linear relationships and complex interactions between factors. In actual scientific research systems, there may be complex relationships of mutual promotion or restraint between influencing factors, which grey relational analysis finds difficult to fully and accurately reveal. For example, there may be a synergistic effect between science and technology investment and the number of scientific researchers. Sufficient investment in science and technology can attract more researchers to participate in projects, while outstanding researchers can more effectively utilize the investment to improve the efficiency of scientific output. However, grey relational analysis cannot directly reflect this synergistic effect.

Future research can be expanded in the following directions: First, to further improve data collection and processing methods. Strengthen communication and collaboration with various data source departments, establish unified data standards and statistical calibers, and ensure the accuracy and completeness of data. For missing data, reasonable data imputation methods can be used, such as data interpolation and machine learning algorithms, to estimate and supplement the missing information. In the case of data gaps in small research institutions, detailed information can be obtained through field surveys and interviews with institutional leaders. Utilize big data technology to expand the channels and scope of data collection, and obtain more implicit data related to scientific research achievements, such as the academic social networks of researchers and the collaboration networks of research projects, to more comprehensively analyze the changes in the number of scientific research achievements and their influencing factors.

Second, to optimize and expand the grey relational analysis model. Combine it with other data analysis methods, such as structural equation modeling and neural networks, to make up for the shortcomings of grey relational analysis in dealing with complex relationships. Structural equation modeling can simultaneously consider the direct and indirect relationships between multiple variables, and can more comprehensively reveal the causal relationships and mechanisms of action between the number of scientific research achievements and various influencing factors. Neural networks have strong non-linear mapping capabilities and can handle complex non-linear relationships. By combining grey relational analysis with neural networks, the accuracy of predicting the number of scientific research achievements can be improved. Introduce time series analysis methods to consider the dynamic changes and lag effects between factors, and conduct in-depth studies on the long-term and short-term impacts of various influencing factors on the number of scientific research achievements. When analyzing the impact of science and technology policy support on the number of scientific research achievements, consider the time lag effect after policy implementation. Through time series analysis methods, more accurately assess the effects of policies on the number of scientific research achievements in different time periods.

Third, to expand the breadth and depth of research. Analyze the differences in the changes and influencing factors of the number of scientific research achievements from multiple dimensions, such as different academic fields and different research subjects. In terms of academic fields, study the changing patterns and influencing factors of the number of scientific research achievements in different fields such as natural sciences, social sciences, and engineering technology, to provide a basis for formulating targeted academic development policies. In terms of research subjects, compare and analyze the characteristics and influencing factors of different research subjects such as universities, research institutes, and enterprises in the process of scientific research output, to promote collaborative innovation among different research subjects. Strengthen the study of the quality of scientific research achievements. Instead of just focusing on the changes in the number of scientific research achievements, delve into the quality evaluation system and influencing factors of scientific research achievements to provide suggestions for improving the overall quality of scientific research achievements in Tai'an City. Combine the industrial development planning and socio-economic development goals of Tai'an City to study the contribution mechanism of scientific research achievements to industrial upgrading and economic growth, and provide decision-making support for the deep integration of scientific and technological innovation with socio-economic development in Tai'an City.

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