Applications of Grey Prediction Method in Intelligence Research: A Review (Postprint)

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Abstract

[Purpose/Significance] Grey prediction methods can effectively handle the widely present small-sample data in intelligence research. By reviewing the application status of grey prediction methods in intelligence research, this study summarizes their deficiencies during application and provides references for their further application in intelligence research.

[Method/Process] Through a comprehensive review of relevant literature on grey prediction methods in intelligence research, this paper outlines their application from the perspectives of data selection, model construction, and problems addressed, summarizes existing issues in current applications, and proposes recommendations for improvement.

[Results/Conclusion] Regarding methodological application, existing research primarily employs sequence grey prediction, with models concentrated on univariate grey prediction models. Depending on the prediction object, grey prediction methods have been well applied in areas including journal analysis, library operation management, hot topic analysis, and scientific institution evaluation. Future research could attempt different grey prediction methods based on the characteristics of the prediction object and research objectives, broadening the application of grey prediction methods to other intelligence research problems.

Full Text

Preamble

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A Review of Grey Prediction Method Applications in Information Research

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Abstract:
[Purpose/Significance] Grey prediction method can effectively handle small-sample data that is widely encountered in information research. By reviewing its application in information research, this paper summarizes existing shortcomings in its application process to provide references for future use. [Method/Process] Through reviewing relevant literature involving grey prediction methods in information research, this paper provides an overview of data selection, model construction, and problem-solving aspects, identifies current problems in the application of grey prediction methods, and proposes improvement suggestions. [Result/Conclusion] In methodological application, existing research primarily adopts sequence grey prediction, with models concentrated on univariate grey prediction models. According to different prediction objects, grey prediction methods have been successfully applied in journal analysis, library operation management, hotspot topic analysis, and research institution evaluation. Future research should attempt different grey prediction methods based on the characteristics of prediction objects and research objectives, expanding the application of grey prediction methods to other information research problems.

Keywords: Grey prediction method; Information research; Data selection; Model construction; Information research problems
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1. Introduction

Prediction, as a common approach in academic research, scientifically forecasts the future development and level of things, thereby providing references for current research and work while guiding future planning. In the information science field, research extends beyond analyzing current states to frequently requiring predictive analysis of future development trends, offering objective and quantitative foundations for scientific decision-making. For instance, library managers must plan future book procurement based on current and projected borrowing patterns; university administrators need to adjust disciplinary development directions according to current and future disciplinary performance; and researchers must understand current research topics and their development trends to continuously refine their work.

After long-term development, more than 300 prediction methods have been accumulated, which can be divided into qualitative and quantitative prediction based on their nature. Quantitative prediction uses statistical methods and

mathematical models to forecast future developments based on quantitative data, 主要包括时间序列法、因果分析法、灰色预测法、人工神经网络、马尔可夫法等. Compared with other quantitative prediction methods that require extensive data, grey prediction methods can effectively handle small-sample incomplete data, achieving relatively accurate predictions with minimal data, thus attracting significant attention across various research fields.

In information research, data scarcity or incompleteness often occurs due to difficulties in data acquisition, hindering subsequent analysis. For example, in analyzing large scientific facilities, most operational data has low public availability and is not updated timely, typically yielding only 5-6 years of operational indicator data—far below the requirements of other prediction methods and making it difficult to study their future performance. Grey prediction methods, however, require as few as four data points to effectively predict small-sample data, offering a new direction for analyzing such data in information research. In fact, scholars applied grey prediction methods to forecast science and technology development trends in information research as early as 1991. Although grey prediction methods have continuously evolved in recent years, their application in information research remains insufficient. Most studies simply apply basic grey prediction models without systematic investigation, resulting in monotonous application methods and limited prediction objects, leaving considerable room for expansion in solving information research problems.

To better organize the application of grey prediction methods in information research, this paper uses Web of Science and CNKI as data sources. We limited research directions to "Information Science & Library Science" and literature categories to "Library and Information Science," using search terms SU=(Information Science & Library Science) AND (TS=((grey predict*) OR (grey forecast*) OR (gray predict*) OR (gray forecast*) OR "GM(1,1)" OR "GM(1,n)")) and SU='grey prediction' + 'grey forecast' + 'GM' (search date: November 15, 2020). After manually reviewing and excluding literature clearly unrelated to information research or not involving grey prediction applications, we conducted backward searches on valuable references, ultimately compiling 44 papers. Based on these, this paper reviews grey prediction methods applied in information research and the problems addressed, analyzes existing issues in practical applications, and provides suggestions for future reference.

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2. Overview of Grey Prediction Methods

In 1982, grey system theory was proposed as a mathematical approach for solving information-incomplete systems, applicable to analyzing small-sample, incomplete-information system problems. Grey prediction methods, a component of grey system theory, predict grey systems with only partially known information. The application process involves two main steps: data selection and model construction. Grey prediction methods can be classified into vari-

ous types based on data selection approaches, with different types applicable to different data sequence characteristics. Model construction establishes corresponding differential equations using selected data to obtain results and can be simply categorized by the number of variables involved.

2.1 Data Selection

The first major step in grey prediction is selecting and processing data for prediction objects. According to Professor Deng Julong's classification in *Grey Theory Foundation*, different grey prediction methods differ in the types of data sequences required for model construction. Therefore, appropriate grey prediction types must be determined based on prediction objectives and object characteristics to guide data selection. Commonly used grey prediction types include sequence grey prediction, catastrophe grey prediction, topological grey prediction, and envelope grey prediction. Sequence grey prediction is currently the most frequently used method, directly employing observed data for research without requiring additional data processing, making it suitable for most sequences. However, catastrophe grey prediction performs better for outlier prediction, requiring extraction of outlier sequences from original data for study. Topological and envelope grey predictions are more suitable for sequences with large fluctuations—the former selects time series based on point-set topology, while the latter requires constructing upper and lower boundaries of original sequences.

2.2 Model Construction

The second major step is constructing grey prediction models for calculation using processed data. Grey prediction models have evolved to include many mature models, which can be broadly divided into two categories: univariate grey prediction models represented by the GM(1,1) model, and multivariate grey prediction models represented by the GM(1,N) model. Different model types can be selected based on the number of variables involved in the research.

2.2.1 Univariate Grey Prediction Models Univariate grey prediction models reveal internal development patterns through single-variable first-order differential equation models, primarily applied to modeling and predicting single time series. Deng Julong's GM(1,1) model is the most classical univariate grey prediction model, possessing mathematical properties such as additivity, difference, and differentiation. However, research indicates that the GM(1,1) model may produce significant deviations under certain prediction conditions. Consequently, a series of improved GM(1,1) models have been derived, such as Liu Sifeng's introduction of practical buffer operators into the GM(1,1) model, Xie Naiming et al.'s DGM(1,1) model, and the further-developed NDGM(1,1) model capable of solving non-homogeneous approximate exponential sequence prediction problems.

2.2.2 Multivariate Grey Prediction Models Multivariate grey prediction models effectively overcome the limitation of univariate models that consider only one characteristic parameter or several parameters separately. However, multivariate grey models are currently mainly used to analyze the closeness between system characteristic sequences and related factor sequences, with fewer applications in prediction. The GM(1,N) model considers systems composed of multiple interacting factors and is the classic multivariate grey prediction model. Due to its relatively complex solution, models such as MGM(1,N), grey convolution GMC(1,N), and KGM(1,N) have been developed to address this issue and improve prediction accuracy.

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3. Grey Prediction Methods Applied in Information Research

3.1 Data Selection

From a data selection perspective, current information research basically employs sequence grey prediction, directly using observed sequences for prediction without additional data selection and processing. For example, X. Dong et al. predicted the average impact factor of TOP20 management journals from 2014-2018 based on collected data from 2004-2013; Ge Fan directly applied collected library borrowing data from 2007-2016 to construct and predict using the GM(1,1) model; and Su Guangyao applied sequence grey prediction to forecast paper quantity, total citations, and average citations per paper over ten years.

Some studies have noted that sequence grey prediction performs poorly with non-monotonic sequences and have attempted other grey prediction types for data extraction and processing. Zhang Liang et al. pointed out that library book purchasing volume is a typical fluctuating sequence, constructing upper and lower boundaries for a small library's purchasing volume and applying envelope grey prediction for analysis. Zhang Liang et al. also introduced time variables into traditional two-dimensional envelope prediction, proposing three-dimensional envelope grey prediction for library literature knowledge element data. This method considers time variation when constructing boundaries, avoiding potential envelope overlap and improving prediction accuracy for fluctuating data.

3.2 Model Construction

3.2.1 Univariate Grey Prediction Models Univariate grey prediction models are the most widely used grey prediction models in information research. Existing studies have concentrated on univariate models, particularly the GM(1,1) model. For instance, Zhu Lin's prediction of library performance, Zhang Ning's prediction of data research hotspot topics, and Song Yan's prediction of library literature borrowing volumes all applied the GM(1,1) model. Although simple to apply, the GM(1,1) model has many restrictions on

prediction data, being suitable only for exponential data fitting and prediction. However, many studies often ignore this limitation, simply applying the model without analyzing whether data possesses exponential characteristics. While the GM(1,1) model demonstrates good short-term prediction effects, it may produce predicted values far exceeding actual values in long-term prediction, making it unsuitable for direct long-term application.

To address the poor long-term prediction performance of the GM(1,1) model, some scholars have introduced the metabolic GM(1,1) model. This model considers random disturbance factors generated by time, placing the predicted next-year data at the end of the original sequence while removing the oldest data to form a new time series, thereby improving long-term prediction accuracy to some extent. Qian Lingfei and Yang Jianlin confirmed in disciplinary innovation capability prediction that the metabolic GM(1,1) model's long-term prediction accuracy is significantly higher than direct GM(1,1) application. Y. Chen similarly used the metabolic GM(1,1) model to handle time disturbances in library data service paper quantity prediction. Other studies applying metabolic GM(1,1) include Chen Ying et al.'s library borrowing data prediction and Tan Bo et al.'s national reading survey data prediction. Chang Liang et al.'s equal-dimensional grey number supplementary GM(1,1) model in scientific output prediction also belongs to metabolic models. Notably, metabolic models remain essentially GM(1,1) models—exponential models suitable only for exponential sequence prediction.

Given the GM(1,1) model's weak prediction capability for non-smooth data, smoothing original data can effectively improve prediction accuracy. Xu Yang et al. applied logarithmic operators to preprocess data before GM(1,1) modeling in information science hotspot topic prediction. While logarithmic transformation is simple and convenient, its smoothing effect is not obvious. Shi Liang constructed four types of weakening buffer operators to act on initial data, weakening distortion caused by impact disturbances and effectively improving prediction accuracy for university potential disciplines. Weakening buffer operators, as common data processing methods in prediction, demonstrate excellent performance in data smoothing, and combining different buffer operators can further enhance data smoothness. Fu Xinhe et al. approached from both data preprocessing and model construction perspectives: they introduced difference-weighted smoothing processing to greatly improve data smoothness, and addressed errors introduced by traditional grey prediction models through Euler correction, enabling the improved model to accurately predict library borrowing volumes with low smoothness.

In fact, most data involved in prediction research are non-homogeneous. Prediction results based solely on GM(1,1) models with data smoothing and error correction are unsatisfactory. To effectively handle non-homogeneous data, the NDGM(1,1) model was proposed. S. A. Javed et al. introduced this model to information research, using it to predict publication quantities from 2016-2025 for the US, China, India, and Brazil based on 2005-2015 data, demonstrating

its superior performance over GM(1,1) for non-homogeneous sequences.

Some studies have also attempted to combine grey prediction with other methods to further improve accuracy. To enhance nonlinear data processing capabilities, some research combined GM(1,1) with neural networks to predict library borrowing volumes and book copy quantities. Others applied regression methods to grey prediction, such as Wang Juping et al., who used quadratic regression and GM(1,1) models separately to predict book purchase funds, then combined results using Induced Ordered Weighted Averaging (IOWA) operators. Liu Subing et al. combined GM(1,1) with linear regression models using "minimum sum of squared errors" as the optimization criterion for library borrowing volume prediction.

To address large data fluctuations that reduce grey prediction accuracy, Markov chains have been introduced. Duan Weihong applied the GM(1,1)-Markov model to predict per capita borrowing volumes and collection utilization rates. Bao Hong et al. further combined unbiased GM(1,1) with Markov chains to predict book loss rates and borrowing volumes. Combined models showed improved prediction accuracy and expanded applicability, though combinations remained simple GM(1,1) integrations. Despite relatively rich applications of univariate grey prediction models in information research, they cannot consider factors related to prediction variables, affecting prediction scientificity and accuracy to some extent.

3.2.2 Multivariate Grey Prediction Models Due to solution complexity, multivariate grey prediction models have been rarely applied in prediction research. However, recent studies have attempted their use, comprehensively considering relevant factors affecting prediction objects to improve accuracy.

Studies involving multivariate models include Zhang Wende et al.'s analysis of people's mediation information, which applied the GM(1,N) model to predict national dispute resolution cases. To improve accuracy, they also combined GM(1,N) with regression methods for more effective prediction. Teng Jie et al. integrated metabolic concepts with GM(1,N) and introduced Markov chain prediction methods to construct a GM(1,N)-Markov dynamic model. Analyzing two popular negative public opinion topics—the "Changsheng Bio vaccine incident" and "Beijing Red-Yellow-Blue kindergarten abuse incident"—they predicted and validated Baidu Index trends, demonstrating better applicability than the GM(1,N) model alone.

Overall, multivariate grey prediction models remain relatively underapplied in information research, with existing applications essentially being simple combinations of GM(1,N) with other prediction methods.

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4. Information Research Problems Solved by Grey Prediction Methods

Based on existing research, grey prediction methods have been well applied in journal analysis, library operation management, hotspot topic analysis, and research institution evaluation.

4.1 Journal Analysis

In information research, predictive analysis of journals and their characteristics can effectively reflect development trends, providing references and insights for future journal work. Early applications of grey prediction methods in information research focused primarily on journal indicator analysis. For example, Chen Quan predicted journal publication quantities for 2000-2005 based on 1990-1999 data; Yao Hong predicted average impact factor values for 2001-2004 based on 1997-2000 Chinese scientific journal data; and Wang Yun constructed a half-life indicator to measure the aging of *Acta Mathematica* and predicted its future aging based on five years of known data using the GM(1,1) model.

However, grey prediction applications for journals have mainly concentrated before 2010, focusing on traditional indicators such as journal quantity, impact factor, and aging parameters. In recent years, while journal quantitative indicators have become increasingly abundant, grey prediction methods have not been applied to these new metrics.

4.2 Library Operation Management

Library operation management has long been a focus of scholarly attention. Research has expanded from analyzing quantitative indicators of library operations to predicting relevant metrics to guide future library planning. Grey prediction methods are among the most common approaches in library operation management research.

Common research content includes predicting book borrowing volumes, typically using 6-8 periods of borrowing data with GM(1,1) models. Studies have also predicted library expenditure, book purchasing quantities, and library operational performance. With the popularization of e-books, scholars have applied grey prediction methods to study e-book click and download volumes. Additionally, Bao Hong et al. predicted new and old book loss rates, while Liu Chi predicted book rejection rates and average copy quantities.

Despite early and long-standing applications in libraries, prediction objects remain largely limited to traditional operational management indicators such as borrowing volume, purchasing quantity, and library funding. However, with increasing digitalization and public knowledge levels, library operation management encompasses growing content including activity organization, online platform construction, and document delivery services—all generating substantial process and outcome data that could provide references for future library

management if analyzed through grey prediction.

4.3 Hotspot Topic Analysis

Predicting hotspot topics in a field or discipline can summarize future development trends, providing references for research directions and ideas. Before 2010, hotspot topic prediction focused more on literature quantity, using database search results to represent research 热度. With mature natural language processing technology, numerous topic identification and processing methods have been introduced, shifting hotspot topic prediction from literature quantity to keyword and subject term analysis.

Xu Yang et al. applied GM(1,1) models to calculate data for eight representative keywords from nine major information science journals during 2010-2014, predicting future frequencies of these hotspot topics over the next two years. Zhang Ning et al. focused on data research topics, using grey prediction methods to calculate six hotspot keyword clusters from 18 library and information science journals during 2012-2016, predicting future research 热度 and discussing future hotspots in the data field. Wang Yu et al. used GM(1,1) models to quantitatively predict term frequency data for four major topics in the smart library field from 2010-2018 in the CNKI database, achieving trend predictions.

Notably, while hotspot topic analysis has become a key application area for grey prediction methods in recent years, emerging topic analysis—another branch of disciplinary topic research—has not yet seen grey prediction application. Compared with hotspot prediction, emerging topic prediction emphasizes novelty and development potential, which is crucial for adjusting research plans and improving scientific decision-making, making it worthy of future grey prediction research attempts.

4.4 Research Institution Evaluation

With national emphasis on building world-class universities and disciplines, domestic institutions have conducted evaluations to guide future development and disciplinary layout. Scholars have also predicted development trends of institutions and disciplines to serve decision-makers' planning needs and improve resource allocation efficiency.

Regarding research construction, Dong Fenyi et al. used GM(1,1) models to predict nine indicators including university patent applications, scientific activity personnel, R&D institutions, and scientific funding. Shi Liang used grey prediction methods based on the "Wu Shulian Chinese University Ranking" to analyze research competitiveness indices of top 10 universities from 2012-2018, predicting trends for 2019-2021.

Predicting potential disciplines has become a major application direction. Qin Ping et al. used GM(1,1) models based on 2004-2013 InCites data for eight disciplines at Nanjing University of Aeronautics and Astronautics not yet in ESI

rankings, predicting high-level paper development trends and comparing total citation predictions with ESI database minimum values to estimate when potential disciplines might enter the top 1% globally. Dai Ying similarly used grey prediction methods with ESI and InCites databases to predict and analyze indicators for potential disciplines at Hefei University of Technology. Su Guangyao applied grey prediction to forecast potential discipline development at Zhejiang Gongshang University.

However, research institution evaluation is relatively complex, encompassing teaching, research, infrastructure, and other aspects. Current applications have focused on research construction processes, with grey prediction methods not yet applied to other evaluation perspectives such as teaching quality, internationalization level, infrastructure, and knowledge transfer capabilities. Expanding grey prediction to these areas would enable comprehensive evaluation of university research capabilities.

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5. Existing Problems and Improvements in Application

5.1 Relatively Monotonous Data Selection

Currently, grey prediction types applied in information research basically belong to sequence grey prediction, indicating monotonous data selection. Other grey prediction types are rarely seen, with only references [22-23] involving envelope grey prediction. While sequence grey prediction can be directly applied to observed sequence data in most cases, it performs poorly in predicting abnormal or highly fluctuating values. In contrast, catastrophe grey prediction, topological grey prediction, and other types offer advantages.

Catastrophe grey prediction forecasts outlier timing and has been widely applied in other fields—for example, predicting pest occurrence times in agriculture and abnormal price timings in economics. Information research also contains substantial abnormal data, such as sudden increases in keyword search volumes on certain dates. Effective prediction of when these outliers will next occur could enable advance deployment of system operational capacity.

Unlike sequence grey prediction, which mainly applies to monotonic sequences, topological grey prediction targets large-fluctuation sequences. In information research, cross-domain periodic fluctuations in online public opinion are relevant. Xie Kefan et al. noted that online public opinion typically experiences five stages: incubation, germination, acceleration, maturity, and decline. Consequently, keyword search volumes for specific online events constitute typical large-fluctuation sequences, some with periodicity. The Baidu Index for the "Changsheng Bio vaccine incident" and "Beijing Red-Yellow-Blue kindergarten abuse incident" represent typical fluctuating data. Applying topological grey prediction could more accurately capture future trends. Additionally, library

borrowing volumes and specific topic keyword frequencies are common fluctuating data in information research.

Envelope grey prediction, system grey prediction, and other types also outperform sequence grey prediction in certain contexts. Actual research should select appropriate data sequences based on prediction object characteristics and objectives.

5.2 Relatively Basic Model Construction

Current grey prediction applications in information research focus primarily on univariate grey prediction models, particularly GM(1,1). Although some studies involve improved grey prediction models, they essentially remain simple combinations of GM(1,1) with other data processing or quantitative prediction methods. Other grey prediction models are rarely seen, resulting in relatively basic model construction that affects prediction accuracy to some extent.

While some studies have noted suitable data types for models, most only address data preprocessing without selecting more appropriate grey prediction models for data characteristics. Compared with GM(1,1), which mainly applies to exponential data, models such as DGM(1,1) and NDGM(1,1) with lower exponential requirements should be considered for future research.

Additionally, Professor Deng Julong noted that most prediction data are nonlinear, with literature growth and citation frequency changes often being nonlinear sequences. However, GM(1,1) has weak nonlinear processing capabilities. Although some studies have combined GM(1,1) with neural networks for nonlinear data with satisfactory results, introducing grey prediction models suitable for nonlinear data and combining them with neural networks could further improve capabilities. Common nonlinear grey prediction models include nonlinear GM(1,1,α), nonlinear optimized GM(1,N), and KGM(1,N) models.

Multivariate grey model applications also warrant attention. In practice, prediction objects are often associated with numerous factors. Univariate models consider only the prediction object itself, failing to reflect inter-variable influences and coordinated development, whereas multivariate models can explore relationships among multiple variables. Therefore, information research should consider introducing multivariate grey models. Reference [35] used NDGM(1,1) to predict national publication quantities, though a country's publications are likely related to research strength, investment, and researcher numbers. Introducing multivariate grey models incorporating these factors could further improve prediction scientificity and accuracy.

5.3 Relatively Limited Problem Scope

Current grey prediction applications in information research are largely limited to journal analysis, library operation management, hotspot topic analysis, and partial research institution evaluation content. The scope of solved problems

is relatively limited, with research content requiring further enrichment and attempts.

On one hand, applications in these four areas can be further deepened. Current journal analysis remains at the simplest level of predicting journal quantity, aging parameters, and impact factors. In recent years, new journal evaluation indicators have emerged, such as the SJR index (SCImago Journal Rank), Eigenfactor Scores, and I3 indicators, along with Altmetrics-based alternative metrics. Future journal predictions could analyze these new quantitative indicators.

Library operation management predictions have focused primarily on borrowing volume and funding expenditure. However, with increasing digitalization and public knowledge levels, library operation management encompasses growing content such as activity organization, online platform construction, and document delivery services—all generating substantial data suitable for grey prediction analysis to provide management references.

Hotspot topic research is currently the focus of grey prediction applications, yet emerging topic prediction remains unexplored. Compared with hotspot prediction, emerging topic prediction emphasizes novelty and development potential, which is crucial for adjusting research plans and improving scientific decision-making, warranting attempts in grey prediction research.

Research institution evaluation applications have focused on research construction and potential discipline prediction. In fact, institution evaluation also includes teaching quality, internationalization level, infrastructure, and knowledge transfer capabilities. Grey prediction methods could be applied to these other aspects for comprehensive evaluation.

On the other hand, grey prediction applications in information research could be expanded to new domains. Scholar influence prediction provides references for academic decision-making and career planning, with current methods focusing on regression analysis and neural networks. For younger scholars with limited influence indicator data, grey prediction would be an excellent choice. Grey prediction application in disruptive technology prediction is also worth attempting, as current methods mainly involve neural networks and time series prediction. However, the shortening timeline from theoretical formation to widespread use of disruptive technologies results in only a few years of indicator data—making grey prediction suitable for improving prediction accuracy with such small samples. Additionally, interdisciplinary prediction, research collaboration prediction, and academic rising star prediction are focal points in recent information prediction research but have not yet involved grey prediction methods, representing promising expansion directions.

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Review on the Application of Grey Prediction Method in Information Research

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Abstract:
[Purpose/Significance] Grey prediction method can effectively deal with small-sample data widely existing in information research. By analyzing its application in information research and summarizing shortcomings in the application process, this paper provides references for further application. [Method/Process] By reviewing relevant literature on grey prediction methods in information research, this paper overviews data selection, model construction, and problem-solving aspects, summarizes existing problems, and proposes improvement suggestions. [Result/Conclusion] In methodological application, research mainly adopts sequence grey prediction, focusing on univariate grey prediction models. According to different prediction objects, grey prediction methods have been well applied in journal analysis, library operation management, hotspot topic analysis, and research institution evaluation. Future research should attempt different grey prediction methods based on object characteristics and research goals, expanding applications to other information research problems.

Keywords: grey prediction method; information research; data selection; model construction; information research problems

Note: Figure translations are in progress. See original paper for figures.