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Abstract Book

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ABSTRACT BOOK

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ABSTRACT BOOK

Multi-attribute Decision Analysis On Three-parameter Interval Grey Number Based On “U”-shaped Possibility

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ABSTRACT

The grey target decision method has become an important method for solving uncertainty decision problems due to its unique advantages. Due to the complexity and uncertainty of real-world environments, it is more in line with the actual situation to use three-parameter interval grey numbers to describe decision problems. This paper focuses on situations where background information exhibits a “U”-shaped distribution and constructs a grey target decision making model based on “U”-shaped three-parameter interval grey numbers. First, for cases in which attribute values follow a “U”-shaped distribution, the concepts of the “U”-shaped three-parameter interval grey number and its possibility function are defined to characterize the “minimum grey point” with the lowest probability of taking a value in the interval. Then, a distance measurement formula for “U”-shaped three-parameter interval grey numbers is given. On this basis, a grey target decision making model is constructed. Finally, the proposed model is verified by taking the concurrent number of electronic resources purchased by a university library as an example. The case results confirm the rationality, scientific soundness, and effectiveness of the proposed model.

Keywords:
Multi-attribute decision making; Grey target decision making; Three-parameter interval grey number; “U”-shaped distribution

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A novel grey interactive difference relational analysis model for high-quality development assessment

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ABSTRACT
Grey relational analysis (GRA) is a core component of grey system theory (GST). However, existing GRA models for panel data suffer from several limitations, including insufficient representation of indicator interactions, inadequate characterization of data development trends, and sensitivity to the ordering of indicators. To address these issues, a grey interactive difference relational analysis model (GIDRA) is proposed. First, the sample matrix is decomposed into indicator vectors and time vectors. Based on this decomposition, interaction difference matrix at each time point and development difference matrix for each indicator are constructed. Then, the eigenvalues of both matrices are calculated to measure the variation in indicators and over time. These eigenvalues are used to derive the grey interactive and development difference relational coefficients. Subsequently, the indicator-based grey relational degree and the time-based grey relational degree are defined, and a weighted average of the two is used to compute the grey interactive differentiated relational degree. The proposed GRA model satisfies several desirable properties, including normality, symmetry, invariance to the ordering of indicators, and translation invariance of the relational degree. Finally, the model is applied to assess high-quality development across nine cities in the Yellow River Basin in Shandong Province. The results demonstrate the rationality of the proposed model, and its robustness is further verified through a stability analysis and comparative analysis.

Keywords:
Grey relational analysis, Grey system, Interactive difference, Panel data

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A new time-varying oscillatory fractional-order TFOGM(1,N,r_i) power model and its application

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ABSTRACT

A new time-varying oscillatory fractional-order TFOGM(1,Nr_i) power model is proposed for time series prediction problems with periodic oscillations and nonlinear trends and uncertain sequences of system behavior characteristics. Firstly, based on the idea of fractional order, the adaptive adjustment of the cumulative order of the independent variable and the dependent variable was achieved. Then, trigonometric functions containing rounding functions and time power terms are introduced to simulate the oscillation and nonlinear characteristics of the time series, in order to improve the prediction accuracy of the model; Secondly, by introducing dummy variables to quantify the policy impact, the theoretical framework of the model is made closer to the logic of reality. Finally, this model was applied to the simulation and prediction of monthly carbon dioxide emissions in China and compared with other commonly used models. The results show that this model has good practicability and reliability.

Keywords:

Grey multivariate prediction; Fractional order accumulation; Virtual variable; Periodic oscillation; Carbon emissions

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A novel seasonal time-varying discrete grey power model and its application in solar power generation forecasting

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ABSTRACT

Accurate forecasting of solar power generation plays a pivotal role in optimizing the national energy structure, enhancing the economic viability of the power system, and promoting the sustainable development of renewable energy. Solar power generation exhibits significant time-varying seasonal fluctuations and nonlinear trends, which pose a challenge to existing forecasting techniques. Therefore, this paper proposes a novel seasonal time-varying discrete grey power model for solar power generation forecasting. The model innovatively couples seasonal time trend terms, dummy variables, and power index to ensure that the model captures seasonal, nonlinear, and time-varying features in the data series. Furthermore, a hiking optimization algorithm (HOA) is employed for hyperparameter tuning. In order to verify the model performance, the United States quarterly and China monthly solar power generation data are selected as empirical cases, and compared and analyzed with mainstream statistical models, machine learning models and grey forecasting models. Finally, the extrapolated forecasts of quarterly and monthly solar power generation for the two countries in 2025-2026 are conducted, and the results show that: (1) the new model demonstrates strong competitiveness among all the compared models, confirming its rationality, validity and superiority. (2) HOA shows good applicability and effectiveness in model hyperparameter optimization. (3) It is predicted that the solar power generation of the two countries will maintain strong growth during 2025-2026, with China showing a significant lead in both total power generation and growth rate.

Keywords:
Grey forecasting model; Seasonal; Solar power generation; Optimization algorithm

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Optimal strategies for a multi-tier closed loop supply chain considering power structure and the interaction between consumers' dual preferences

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ABSTRACT

Consumers' preferences for online or offline channels and for new or remanufactured products significantly influence the optimal strategies of CLSC members. To explore the impacts of their interaction, this paper designs a multi-tier closed-loop supply chain (MCLSC) considering power structure and the interaction between consumers' preferences for channels and products. Subsequently, it develops three decentralized Stackelberg game models to determine optimal pricing strategies, member profits, and overall profit in MCLSC: manufacturer-led (M), retailer-led (R), and recycler-led (T) models. Additionally, it also analyzes the impacts of power structures and key parameters, such as the collection rate of used products, consumers' preference for online channels, and consumers' preference for new products, on above optimal decisions. Finally, a real case of auto starter MCLSC is conducted to verify the proposed models. Research results reveal: 1) As consumers' preference for online channels (or new products) increases, so do the optimal wholesale and retail prices in the online channels (or for new products). Furthermore, manufacturer, retailer, and the entire MCLSC achieve optimal profits which follow a U-shaped curve with a minimum when consumers' preference for online channels equals 0.5 (or the preferences for new products reaches a certain value). 2) Optimal recycler profit increases with collection rate, while optimal profits for other member decrease, resulting in profit conflicts among MCLSC members. 3) The M and R models can achieve the lowest retail prices while maximizing MCLSC's overall profit under certain conditions. Furthermore, it is counterintuitive that the T model has the lowest optimal recycler profit and overall profit of MCLSC in all three models.

Keywords:

Closed-loop supply chain; Power structure; Consumers' preferences for online channels; Consumers' preferences for new products; Stackelberg game

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Coal Consumption Forecasting Considering Low-Carbon City Pilot Policies-Based on Improved Gray Forecasting Model with Dummy Variables

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ABSTRACT

Energy has a central position in national social development, and the forecast of coal consumption, as a major component of China's energy consumption, is crucial for energy structure adjustment and green economy transformation. In this paper, a new multivariate gray prediction model, SIVCGM(1,N), is proposed for the long-term impact of low-carbon city pilot policies on coal consumption. The model introduces dummy variables by multiplication-addition mixture, examines the effects of policies on slope and intercept at the same time, and optimizes the parameters by combining L2 regularization with particle swarm optimization algorithm (PSO), which significantly improves the prediction accuracy and robustness. Taking Inner Mongolia Autonomous Region as an example, this paper compares SIVCGM(1,N) with traditional gray models (e.g., GM(1,N), DVCGM(1,N), SVCGM(1,N), and MGM(1,m)) and non-gray models (e.g. linear regression, BP neural network) prediction performance. The empirical results show that the mean absolute percentage error (MAPE) of SIVCGM(1,N) is only 6.11% in the fitting stage, and the MAPE in the forecasting stage is further reduced to 2.8%, which is significantly better than the other models. In addition, the model's prediction of future coal consumption shows that coal consumption in Inner Mongolia will continue to grow from 2023 to 2025, but the growth rate may gradually slow down due to the “dual carbon” policy. This study provides a scientific basis for assessing the long-term effects of the pilot low-carbon city policy, and contributes new ideas for methodological innovation in the field of energy consumption forecasting. The study suggests that Inner Mongolia should promote the optimization of its energy structure and realize a green and low-carbon transition by strictly controlling coal, developing renewable energy, and strengthening carbon emission management while ensuring energy security.

Keywords:

Carbon emission management, Gray prediction, Particle swarm optimization algorithm

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A Novel Grey Procrustes Relational Analysis Model Incorporating Time-Lag Effects

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ABSTRACT
To address the issues in existing grey relational analysis models (GRA), such as the neglect of indicator time lags and data transformation considerations, a novel grey Procrustes relational analysis model (GPRA) is proposed. First, the concepts of the sample matrix, time-lag matrix, and the corresponding trimming matrix are introduced. Second, singular value analysis is performed on the relevant matrices, and the optimal rotation matrix is derived. Then, an optimization model is constructed with the goal of minimizing the Procrustes dissimilarity, through which the time lags between indicators are determined. And then, a PD-GRA model is proposed based on the optimal Procrustes dissimilarity with time lag. Finally, the GPRA model is used to analyze the driving factors of AQI in the Yellow River Basin, identifying urbanization rate (UR), carbon emissions (CE), gross domestic product (GDP), and the growth of total investments in fixed assets (GIFA) as the main drivers. The results demonstrate the rationality and effectiveness of the proposed GPRA model, and its advantages are further highlighted through comparative analysis.

Keywords:
Grey Relational Analysis, Procrustes Dissimilarity, Time Lag, Panel Data

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Risk Analysis of Prefabricated Construction Project Based on Grey Cluster Evaluation Model

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ABSTRACT

To meet the "double carbon" strategy, prefabricated building has emerged as a crucial component in the green and low-carbon transformation of the construction industry. Facing dynamic challenges such as technological iteration, policy fluctuations, complexity due to lack of supply chain coordination, and incomplete information from emerging technologies, this paper employs the Grey Clustering Evaluation Model (GCEM) to conduct a dynamic risk assessment of prefabricated construction projects. Through literature analysis, a list of "policy-technology-supply chain" linked risks is compiled, encompassing secondary dynamic risk indicators like policy adjustment frequency and supply chain coordination efficiency. The Grey clustering model is utilized to address issues of small samples, poor information, and multi-factor interactions, with the entropy weight method employed to modify the G1 method for optimized weight distribution. The effectiveness of the model in identifying dynamic risks is validated through practical case studies of prefabricated engineering projects, and corresponding control measures are proposed: strengthening communication with government departments at the policy level, implementing a performance system to retain technical talents, and utilizing big data technology for real-time data collection across all supply chain links. This paper's innovations include constructing a multi-dimensional dynamic risk index, extending the application of the Grey clustering model in dynamic risk tracking and multi-stage decision-making, and proposing a collaborative control path for "policy-technology-supply chain" to assist the green development of the construction industry.

Keywords:

Prefabricated building; Grey cluster evaluation model; Risk analysis; Dynamic risk

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Unveiling Corporate Involution in Manufacturing: A Grey-DANP and System Dynamics Approach to Multidimensional Measurement, Mechanism Analysis, and Governance

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ABSTRACT

Effectively measuring corporate involutionary behavior is critical for mitigating involutionary vicious competition and advancing high-quality development in the manufacturing sector. Existing research predominantly offers qualitative descriptions of the emergence, consequences, and governance countermeasures of corporate involution, with scant attention to its systematic deconstruction, measurement methodology development, and underlying mechanisms. Drawing on the functional alienation perspective of dynamic capability theory, this study innovatively proposes a four-dimensional theoretical framework encompassing "Resource-Technology-Organization-Market"(TROM). Utilizing data from A-share listed manufacturing enterprises in China (2015–2022), we employ the Grey-DANP (GDANP) comprehensive evaluation method to effectively identify corporate involutionary behavior. System dynamics modeling is further applied to systematically investigate the nonlinear transmission mechanisms, threshold effects, and policy intervention outcomes among the four sub-dimensions of involution. The results indicate that: (1) Market involution serves as the key driver, acting upon resource involution through the mediation of organizational involution and technological involution; (2) Positive interrelationships exist among technological involution, organizational involution, and resource involution, collectively exerting a positive influence on market involution. This influence intensifies over time, with the marginal effect increasing sharply once a specific duration threshold is exceeded; (3) Policy scenario simulations reveal that interventions targeting the organizational, technological, and resource dimensions significantly reduce market involution. Conversely, direct intervention in the market dimension proves counterproductive, further escalating market involution levels. This paper applies Grey-DANP for the first time to involution measurement, resolving challenges of fuzzy indicators and complex interdependencies; uncovers the "capability trap" mechanism driven by dynamic capability alienation, extending grey system theory to organizational behavior research; and develops a system dynamics model for governance pathway optimization in complex scenarios. These findings advance the scientific understanding of corporate involutionary behavior dynamics, complementing theoretical research on corporate involution while establishing a theoretical-practical framework for system-level governance.

Keywords:

Corporate Involutionary Behavior, Grey-DANP (GDANP), System Dynamics, Dynamic Capability Trap, TROM Mode.

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Determination Method and Multi-Domain Extension of GM(1,1) Exponent Term Coefficient Based on Error Minimization

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ABSTRACT

To address the adaptability limitations caused by the fixed exponent term coefficient in the standard Grey Model First-Order One-Variable (GM(1,1)), this study proposes an optimization framework for exponent term coefficient based on the error minimization criterion. By constructing an evaluation system with Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) as joint optimization objectives, the optimal solution is explored within the exponent term coefficient interval [-3,3] (using Grid Search and Artificial Fish Swarm Algorithm (AFSA) as dual-path optimization strategies). Key findings include: 1. The exponent term coefficient optimization significantly enhances model performance: Compared with the standard GM(1,1) model, the Improved Grey Power Model (IGPM) achieves notable improvements in prediction accuracy (with average reductions in MAPE and RMSE reaching 37.5% and 38.0%, respectively). 2. The optimization method exhibits robustness: Both Grid Search and ASFA effectively locate nearoptimal solutions for this optimization problem, with their final model accuracy performances being comparable. To validate the method's general applicability, it was successfully applied to two major fields: annual power generation forecasting and metal fatigue strength fitting. Empirical results demonstrate that this exponent term coefficient optimization framework effectively enhances the GM(1,1)'s capability to model complex nonlinear systems, providing more accurate and adaptable solutions for multi-domain engineering predictions.

Keywords:

GM(1,1), IGPM, exponent term coefficient optimization, grid search, ASFA, robustness, power generation forecasting, metal fatigue strength

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A Novel Grey Multivariable Prediction Model for Forecasting Electricity Consumption Considering the Accumulative Time Lag Effects from Energy Transition and Technological Innovation

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ABSTRACT

The accurate identification of driven factors and precise prediction of the electricity consumption (EC) are crucial for green economic development and dual-carbon goals. However, existing studies ignore the accumulative time lag effects from energy transition and technological innovation on EC. In order to achieve an accurate prediction, this study proposes a forecasting framework combining feature identification strategy and a novel grey multivariate prediction model. First, 15 potential driven factors are screened from six dimensions, and random forest regression is used to identify the key influencing factors. In addition, time delay factors and its time lag periods are recognized by cross-correlation analysis. The analysis results indicate that time delay factors are fixed asset investment, renewable energy generation proportion and R&D expenditure intensity, and the key driven factors of EC are GDP, electricity generation and energy consumption, with importance coefficients of 0.52, 0.22,0.20, respectively. Secondly, a novel grey multivariate prediction model with accumulative time lag effects is constructed. And the ordinary least squares estimation and nonlinear programmer are utilized to solve the prediction model. In case study, four typical prefectures in China are taken as examples to verify the superiority, validity and robustness of the proposed model. Finally, scenario forecasts of EC for China's 30 provinces and municipalities are conducted for 2023-2030. The regional heterogeneity is emphasized based on prediction results under three scenarios.

Keywords:

Provincial electricity consumption; Accumulative lag effects; Grey multivariable prediction model; Scenario prediction

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China's nuclear power generation forecasting based on a novel prediction framework containing WPD and proposed grey prediction model and LSTM-RF

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ABSTRACT

The time series of nuclear power generation are typically nonlinear, complex, and fluctuating data. Therefore, it is particularly difficult to simulate and predict the nuclear time series accurately. In order to achieve the precise estimations of nuclear power generation, a novel hybrid forecasting framework, consisting of the wavelet packet decomposition (WPD), a novel grey periodic Bernoulli prediction model, Long Short-Term Memory (LSTM) and Random Forest (RF) combined model, is proposed. Firstly, the pre-processed nuclear power generation data are decomposed into sublayer of varying frequencies which are low-frequency and high-frequency sublayers by using the WPD technique. Secondly, the novel grey periodic Bernoulli prediction model is proposed to forecast the low-frequency sublayer. In the proposed grey model, the least squares method is carried out solving the linear parameters, while the particle swarm optimization algorithm is utilized to optimize the nonlinear parameters. In addition, the LSTM-RF combined model is utilized to predict the high-frequency sublayer. Thirdly, the prediction results of the low-frequency sublayer and the high-frequency sublayer are added together to get the final prediction result. Finally, the model put into practice to forecast the China's nuclear power generation to validate its advantages. The findings indicate that the novel forecasting framework outperforms the benchmark models in terms of performance. this model reduces the MAPE by 51.84%, 33.64%, and 43.53% in comparison with other grey models, and by 32.62%, 31.71%, 32.82%, and 39.54% in comparison with the econometric model and machine learning models.

Keywords:
Wavelet Packet Decomposition, Grey Prediction Model, Machine Learning Models, Nuclear Power Generation, Mixed-frequency

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Conceptualizing Dynamic Multi-Level Grey Space for Uncertainty Modeling: A Belief-System-Oriented Framework

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ABSTRACT

This study, situated in the philosophy of science, introduces a novel conceptual and epistemological framework, the Dynamic Multi-Level Grey Space, to expand and deepen the foundational understanding of Grey Systems Theory (GST) by integrating the evolving structure of belief systems. The primary objective is to philosophically reconceptualize the notion of "grey space" as a dynamic and multi-layered epistemic medium that reflects cognitive processes, belief-based interpretations, and the evolving nature of human understanding in the face of incomplete, dynamic, and context-dependent information. In this context, fundamental concepts such as belief, certainty, and uncertainty are first reinterpreted through an epistemological perspective and then modeled using formal mathematical structures. The proposed framework introduces dynamic and multi-level models for key elements of GST, including grey spaces, grey numbers, and degrees of greyness, all of which can evolve over time as new data becomes available and contextual conditions change. As a result, this study shifts GST from a static, flat, and non-interactive paradigm to a dynamic, multi-layered, and interpretive model. This shift allows for a more accurate representation and analysis of uncertainty in real-world conditions, where human cognition and belief systems are inherently structured across multiple levels and continuously evolving. The core innovation of this research lies in offering a cognition-centered model of uncertainty that builds a conceptual bridge between philosophy, epistemology, and formal mathematics. This framework offers a promising foundation for applications in the development of intelligent decision-support systems, the analysis of complex human-centered environments, and the design of interpretable artificial intelligence architectures.

Keywords:
Philosophy of grey systems; Dynamic systems; Uncertainty modeling; Grey space; Belief systems; Decision Support Systems

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A Multivariate Grey Bernoulli Model Based on Damping Accumulation and Its Application in the High-Tech Industry

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ABSTRACT

This paper proposes an improved grey prediction model with a damping trend factor. By integrating a novel accumulated generating operator with the grey Bernoulli model, a multi-variable grey Bernoulli model based on damped accumulation (DANGBM(1,N)) is constructed. The introduction of the damping parameter into the accumulation process allows for assigning greater weight to new information in data preprocessing. Compared with other data generation techniques, the proposed damped accumulation can flexibly adjust the prediction trend of the grey model. This improvement effectively addresses the issue of difficulty in controlling the prediction trend for complex nonlinear systems in existing grey accumulation techniques. Moreover, the optimal hyperparameters of the model are determined using the Particle Swarm Optimization (PSO) algorithm. Finally, the model is applied to the study of the output value of China's high-tech industry. It is found that, compared with five other prediction models, the new model consistently demonstrates superior performance.

Keywords:
Grey prediction; Damped accumulation operator; Grey Bernoulli model; Particle swarm optimization; High-tech industry

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A Fractional Grey Model Based on Fourier Series Residual Correction and Its Application

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ABSTRACT

Against the backdrop of global energy transition and sustainable development, forecasting the total social electricity consumption is of crucial significance for ensuring the security of power supply, optimizing power systems, and promoting the development of a low-carbon economy. Therefore, this paper proposes a fractional grey model based on Fourier series residual correction (FPFGM(1,1)). The model first introduces a fractional accumulation operator on the basis of the traditional GM(1,1) model, and determines the optimal fractional order through particle swarm optimization. Secondly, it uses Fourier series to decompose and correct the model residuals, effectively filtering out noise and capturing the periodic characteristics in the residuals, thereby further improving the prediction accuracy. Firstly, two numerical examples are used to test the proposed model. Then, taking the data of total social electricity consumption in Jiangsu Province from 2017 to 2023 as an example, the traditional GM(1,1) model, the particle swarm optimization-based fractional GM(1,1) model (PFGM(1,1)), and the proposed FPFGM(1,1) model in this paper are applied to verify the superiority of the FPFGM(1,1) model. At the same time, the model is further used to predict the electricity consumption of Jiangsu Province from 2024 to 2026. The results show that the electricity consumption will continue to grow, and accordingly, suggestions such as strengthening energy supply planning, promoting energy conservation and emission reduction, and optimizing the electricity consumption structure are put forward.

Keywords:
Electricity consumption forecasting; Fourier series; residual correction; fractional grey model

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A novel nonlinear discrete multivariable grey prediction model incorporating dynamic spatial proximity effect and its application

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ABSTRACT

Accurate prediction of air pollution concentrations is crucial for air quality management as well as regional synergistic pollution reduction. Air pollutants typically exhibit spatial proximity effects, temporal fluctuations, nonlinear evolutionary patterns, and nonlinear driving relationships between system variables. However, existing forecasting models rarely capture such complex spatiotemporal features in an integrated framework. To bridge this gap, we develop a nonlinear discrete multivariable grey prediction model incorporating dynamic spatial proximity effect. Specifically, first, a spatiotemporal weighted distance is defined to quantify the intensity of proximity effect, and a variance index based on both spatiotemporal distance and system variable disparities is constructed. This index is then integrated into a KNN-based framework for identifying dynamic neighboring spatial units at each time step. Building upon the classical discrete multivariable grey model, a spatial proximity effect term and nonlinear influencing factors driving term are designed, while the grey action quantity is reconstructed via a hybrid of linear and nonlinear temporal functions to jointly characterize complex spatiotemporal feature. Furthermore, a two-stage hybrid optimization strategy, combining Traversal Algorithm with Bayesian optimization, is designed to simultaneously optimize discrete and continuous parameters. The proposed model is validated using quarterly PM2.5 concentration forecasts for Beijing and Zhengzhou. Results demonstrate that it significantly outperforms several leading models. Finally, scenario-based forecasts under pessimistic, baseline, and optimistic reveal that the PM2.5 concentrations in 2025Q3-Q4 will be 24.61-26.69 and 30.54-37.52 μg/m³ for Beijing, and 19.82-26.08 and 33.33-48.12 μg/m³ for Zhengzhou, respectively.

Keywords:
Grey prediction model; dynamic spatial proximity effect; nonlinear; air pollution concentration; spatio-temporal weighted distance

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Regional Risk Profiling in Romania and Moldova: Political and Security Insights via Grey Systems

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ABSTRACT

The present paper aims to explore the impact of assigning different levels of importance to certain political and security indicators on the level of satisfaction of citizens in the counties of Romania and the Republic of Moldova. In a regional context marked by social and institutional changes, understanding how these two dimensions, politics and security, contribute to the perceptions of the population becomes essential for the formulation of effective public policies. Using grey clustering as the main analysis technique, the counties are divided into three groups, depending on the satisfaction felt by citizens. Given the variable weights of the political and security indicators, five different scenarios are used to observe how these changes influence the grouping results. As the weights were higher for political indicators, a higher level of satisfaction was identified at the county level in Romania. Completely different results were observed when high weights were given to security indicators, with the level of satisfaction being higher in the counties of the Republic of Moldova. The analysis highlights the importance of a balance between political and security development in order to increase citizen satisfaction. The results underscore the need for well-targeted policy interventions in counties with low levels of satisfaction in order to improve governance and security conditions.

Keywords:

Regional disparities, grey clustering, placed-based economy, EU periphery, Romania, Republic of Moldova

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Segmenting the Job Market: A Hybrid Grey Clustering–ABM Framework

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ABSTRACT

This paper is oriented towards investigating the changes in Romanian job market, more specifically focusing on examining the employees' skills in computers and information technology sector. Initially, 12 representative competences (Cognitive skills, Basic technical skills, Advanced technical skills, Software development, Cloud computing, Databases, Data analysis, Machine Learning & Deep Learning, Cybersecurity, Programming engineering, Soft skills, and Personal skills) were selected, and then a Google Forms-based online questionnaire was created and distributed for assessing the respondents' skills with respect to the mentioned categories, involving a Likert scale with 5 points. The case study covers the period between November and December 2024 and consists of 154 valid responses from individuals that are either working or looking for a job in the field of computers and information technology. A grey clustering approach was then used for splitting the respondents into multiple categories, considering their core capabilities. Moreover, the actors in the job market were further described based on the information collected from various sources, and a series of hypotheses were made. Finally, a context-specific ABM framework is proposed, including the agent's types, characteristics, and even possible interconnections, while the use of NetLogo software offers an interface which exposes the identified attributes of the agents under consideration. The insights uncovered in this paper represent essential data for the job market sector, highlighting the most common employees' skills, underdeveloped competences, along with the current employers' distribution and key categories of learning suppliers. This information can assist in further expanding the domain and better comprehending how the technology's evolution influences this area.

Keywords:

Job market, grey clustering, agent-based modelling, grey systems theory

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Grey relational analysis model: Application in evaluating digitalisation impact on economic prosperity

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ABSTRACT

Digitalisation has become a critical determinant of a nation's economic development through the adoption and integration of digital technologies in various sectors. The dynamic relationship between digital transformation and economic prosperity has led to a comprehensive examination of the structural and contextual factors shaping national digital ecosystems. This paper aims to bridge the gap in understanding the broader implications of the combined impact of all digital dimensions on economic prosperity in the EU, by considering human capital, connectivity, digital technology integration, and also digital public services, alongside macroeconomic variables like GDP growth rate and Gini index. After a critical comparison of the existing digital composite indexes, the DESI was selected for the investigation, as it allows for the most comprehensive assessment of digitalisation in the EU countries with annual data available up to date. From a methodological perspective, we conduct a Grey Relational Analysis (GRA) to quantify the impact of all DESI factors on economic prosperity of the EU countries, to deal with incomplete or uncertain data, which is often the case in the context of digital economy development. Our findings suggest that digital infrastructure factors, along with digital public services tend to boost economic growth the most, while the GINI index is primarily impacted from an infrastructure perspective only when it comes to mobile internet access and households' internet access. Regarding digital skills, internet use is the most stimulating factor for both economic growth and income inequality reduction in the EU.

Keywords:

Digitalisation, Grey Relational Analysis, Economic growth, Inequality index

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Green Supplier Selection using Grey Systems Theory and Sustainable Multicriteria Decision. A Case Study on Automotive Suppliers

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ABSTRACT

Nowadays, due to the fast development of new companies and technological advancements, the supply chain process it becomes more and more difficult to predict. Supplier selection stands as a key step of supply chain management, which has to take into account the various features such as customer satisfaction, technology that has been used, cost efficiencies or sustainability practices. Using multiple features and applying Grey Systems Theory knowledge, a tool that automatically applies the grey numbers to supplier selection has been defined. The input data consists of a list of suppliers, decision makers and attributes. A total of nine steps has been applied to the data in order to automatically determine the optimum suppliers based on the list of attributes and importance that has been decided by decision makers. The main steps that have been conducted are related to Grey Systems Theory such as defining synthesized rating value calculation, synthesized grey decision matrix, establishing normalized grey decision matrix, calculating mean attribute weight based on decision-makers expertise, calculating the weighted normalized grey decision matrix, describing the ideal supplier sequence of attributes, obtaining the synthesized possibility degree between optimum supplier and each supplier and rank the suppliers. The algorithm was designed using Python Programming language. The output of the analysis consists in a classification of the suppliers based on specific attributes that have been selected.

Keywords:

Green supplier selection, grey systems theory, automotive industry, python programming language

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Towards Balanced Regional Development: A Grey Systems Perspective on Romania's Economic, Social, and Ecological Indicators

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ABSTRACT

The concept of sustainable development emerged from the need to balance economic, ecological, and social plans in order to improve the quality of human life, but also of the planet in the context of ensuring economic growth. The current paper aims to determine how the NUTS3 (Nomenclature of Territorial Units for Statistics, the 41 counties plus Bucharest municipality) regions of Romania are grouped according to the results obtained in 2023 for a series of indicators that were part of three indices intended to describe the three pillars of sustainable development. Thus, using grey clustering, the counties were divided into three classes, the first being characterized by the best performances, the second by average performances, while the last group encapsulated the counties with the worst results. Additionally, several scenarios were created in which the three indices were given various degrees of importance, and the results obtained were subsequently compared. Thus, it was found that weighting the social index with a higher importance coefficient compared to the other two pillars leads to the classification of more counties in cluster III, a sign that there is a problem in this area. Moreover, regardless of the chosen scenario, the capital of the country managed to rank among the counties with the best performances.

Keywords:

Sustainable development, green economy, grey clustering, Romania

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Verification and validation of grey agent based simulation

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ABSTRACT

This study presents the verification and validation process of a simulation model based on the integration of Agent-Based Modeling (ABM) and Grey System Theory (GST) to represent human behavior under conditions of uncertainty. While ABM captures micro-level behaviors such as individuals' location, speed, social interaction, and leader-following, GST processes partial information, missing data, and uncertainty in a quantitative manner and incorporates them into decision-making processes. In the modeling process, agents' orientation, exit selection, and group dynamics during evacuation were optimized using grey clustering and grey relational analysis methods. In the verification phase, the simulation's code and logical structure were examined for compliance with system requirements; in the validation phase, a comparative analysis with similar studies in the literature was conducted, and a GST-based method was developed. The findings demonstrate that grey-based decision mechanisms enhance realism and predictive capability in modeling heterogeneous and uncertain human behaviors. This approach improves the reliability of decision support systems in critical areas such as disaster management, transportation, health crises, and crowd control, while also providing a flexible modeling framework adaptable to various scenarios. The study reveals that the integration of ABM and GST constitutes an effective method for enhancing the accuracy and reliability metrics of complex system simulations.

Keywords:

Agent-Based Modeling (ABM), Grey System Theory (GST), Simulation

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Integrating Sustainability and Industry 4.0 Criteria in ERP Software Selection using Grey OPA

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ABSTRACT

This study proposes an integrated decision-making framework for selecting Sustainable Enterprise Resource Planning (S-ERP) software by incorporating sustainability and Industry 4.0 compatibility criteria under uncertainty. The framework applies the Grey Ordinal Priority Approach (OPA-G) to address indecision, incomplete information, and variability in expert judgments during the selection process. Performance criteria are derived from the literature and structured into economic, environmental, social, and Industry 4.0 compatibility dimensions, including technologies such as cloud computing, artificial intelligence, the Internet of Things, and big data. A case study in the PVC manufacturing sector demonstrates the method's applicability. Results reveal that "System Cost" is the most critical factor, followed by "Quality" and "Financial Situation," while Industry 4.0 technologies rank above several other criteria. The best-performing alternative, ERP_1, narrowly outperforms ERP_2, showing the framework's sensitivity in differentiating options. The proposed approach offers decision-makers a systematic tool to integrate sustainability priorities and technological readiness into ERP selection, thereby aligning business operations with circular economy principles and sustainable development goals.

Keywords:

ERP Selection, Sustainability, Industry 4.0, Grey OPA, Circular Economy

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Comparison of AFL Player Performance Evaluation Systems with the Interval Grey Number Approach

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ABSTRACT

Player ratings play a fundamental role in the decision-making processes of professional sports organizations. In the Australian Football League (AFL), it is common practice to evaluate match performances both subjectively and objectively. The Inside Football Player Ratings (IFPR) system is considered a subjective evaluation method, while the AFL Player Ratings (AFPR) is regarded as an objective assessment. In this study, a dataset covering all players in a total of 1,026 matches played during the 2013–2017 AFL seasons was used. Alongside the player ratings, the dataset also includes nine common performance indicators, player role classifications, player age, and match outcomes, providing a comprehensive view of player performance across multiple seasons. The primary aim of this research is to apply the interval grey number approach to represent seasonal performance scores in both rating systems without engaging in variable selection, thereby preserving the original structure of each system. Interval grey numbers allow for the detection of “grey zones” in player performance by expressing seasonal variation with lower and upper bounds, effectively capturing inherent fluctuations and uncertainty. For each player, seasonal intervals were generated for AFPR and IFPR values, and comparative metrics such as deviation, overlap ratio were calculated to quantify differences between the two systems. The results reveal notable and statistically meaningful differences in the way the two rating systems evaluate player performance over time. These differences suggest that AFPR and IFPR capture distinct aspects of match performance. The study concludes that the interval grey number approach is a valuable analytical tool for modeling uncertainty in sports performance evaluation and for conducting systematic comparisons between alternative rating methodologies in professional sports contexts.

Keywords:
Grey Number Theory, Interval Grey Number, AFPR, IFPR, Performance Analysis, Machine Learning

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Identifying and Prioritizing Critical Success Factors in Ergonomic Project Management Using The Grey-Dematel Method

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ABSTRACT

Introduction

In the era of rapid technological change, ergonomics is no longer confined to adapting workstations to human capabilities but is increasingly seen as a strategic management tool. Ergonomic Project Management (EPM) integrates ergonomics, project management, and organizational change, supporting both safety and innovation. Despite its growing practical relevance, scientific literature on EPM remains fragmented, lacking systematic analyses of critical success factors (CSFs) and their interdependencies.

Objective

This study aims to fill this gap by identifying the CSFs of ergonomic projects and exploring the causal relationships among them. Specifically, it addresses three research questions:

- RQ1: What are the critical success factors in managing ergonomic projects?
- RQ2: What causal relationships exist between these factors?
- RQ3: Which factors act as primary drivers and should be prioritized in EPM?

Background and Literature Review

Previous research highlights that the success of ergonomic projects depends on early integration of ergonomics into the project lifecycle, top-management support, participatory approaches, and the use of continuous improvement cycles. However, most studies remain limited to industry-specific case analyses. Tools such as maturity models exist but do not capture causal relationships among CSFs. The Grey-DEMATEL method offers potential for modeling such interdependencies under conditions of uncertainty but has not yet been applied in the EPM context.

Methodology

The study employs a systemic analysis framework based on the Grey-DEMATEL method. This approach allows for mapping cause–effect relationships between organizational, technical, and social factors influencing EPM outcomes. Data collection combines expert evaluations with literature synthesis to ensure both theoretical grounding and practical relevance.

Expected Contributions

The research is expected to identify and categorize CSFs for ergonomic projects, reveal their hierarchical influence structure, and determine which factors should be considered strategic priorities. Results will contribute to the theoretical development of EPM and provide actionable insights for organizations implementing ergonomics in a structured, project-oriented manner.

Identifying and Prioritizing Critical Success Factors in Ergonomic Project Management Using The Grey-Dematel Method

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ABSTRACT *Cont'*

Implications

Findings will support decision-makers in resource allocation, risk management, and change communication within ergonomic projects. Moreover, they will broaden the application of systemic analysis tools in human-centered project management, fostering organizational resilience, performance, and employee well-being.

Conclusion

By combining ergonomic knowledge with systemic decision-making tools, this study seeks to advance the understanding of EPM as both a research domain and a management practice. It emphasizes the strategic role of ergonomics in shaping sustainable, innovative, and human-centered organizations.

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University workers wellbeing and bournout – qualitative approach with an application of grey relation analysis

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ABSTRACT

The main research problem of this study is to recognize the relationship between the categories that formulated academic employee's wellbeing and selected symptoms of job burnout. University lecturers and researchers are particularly vulnerable to work-related stress from various sources, e.g., related to greater pressure to obtain research funding, a stronger focus on commercial activity and research impact. The social system of studies is defined by uncertain, limited, and usually incomplete information about the factors that actually cause desirable changes in the system. Therefore, in this study, the Grey Incidences Analysis is applied to analyze which factors of wellbeing have more effects on the future state of employee burnout than others. In addition, the synthetic approach to values of degree of grey incidence facilitates recognition of the burnout symptoms that have a strong relationship with the condition of employees. The researcher's wellbeing is measured using an Oxford Happiness Questionnaire (OHQ) and the job burnout is studied following Oldenburg Burnout Inventory (OLBI). The research sample (n=254) is classified into separated groups using the foundation of self-care and the intensity of physical activity as classification criteria. As a result, the elements that constitute the employee's wellbeing (X_1, X_2, …., X_{29}) are ranked based on the value of their relationship with the categories that constitute the feeling of burnout at work (Y_1, Y_2, …, Y_{16}). The ranking of the wellbeing factors that have the highest impact on burnout is presented and a comparative analysis of the results obtained for distinguished classes of academic workers is conducted. In general, it is noticed that elements such as employees mental alert (X_{21}), commitment and participation (X_8), feeling of having a good influence on events (X_{26}) and a cheerful effect on others (X_{16}) have the highest relation with burnout. Especially, they might change the symptoms of job burnout such as, among others, finding new and interesting aspects in the work (Y_1), managing the amount of the work well (Y_{14}) and feeling energized when working (Y_{16}). The presented ranking indicates which symptoms of academic workers burnout might be eliminated by improving specified wellbeing factors, while indicating burnout symptoms less related to wellbeing, which should be controlled applying a different managerial approach.

Keywords:
Well-being; burnout; happiness; physical activity; university workers; engineers; grey incidence analysis

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Market Sophistication in North Africa and West Asia: Future Performance Projection with Grey System Theories

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ABSTRACT

Global innovation has emerged as a strategic lever that accelerates countries' economic growth, enhances competitiveness, and supports sustainable development. The market sophistication pillar of the Global Innovation Index reflects countries' capacity to attract investment, support entrepreneurship, and commercialize innovative ideas, and thus holds critical importance. This study develops future performance projections for the market sophistication of North Africa and West Asia country groups. Market sophistication is examined through three core criteria: credit, investment, and trade/market scale. Using the base Grey Prediction model GM(1,1) within Grey Systems Theory and 2020–2024 data, we obtain prediction values up to 2027. In 8 out of 16 countries, the absolute error remains below 20%, demonstrating the reliability of predictions; for these countries, projections for 2027 are provided. Based on the predicted values, we then rank countries' average performance as of 2027 using Grey Relational Analysis (GRA), a method grounded in Grey Systems Theory. We also compute a performance ranking using the last five-year average as of 2024. In this way, both current performance and forward-looking performance projections are comparatively evaluated. Overall, the study reduces uncertainty surrounding countries' future market sophistication within the scope of global innovation and contributes to better-informed and more strategic decision-making. Policymakers and institutions can foresee risks and seize opportunities, building stronger roadmaps for sustainable growth, competitiveness, and social welfare. Furthermore, by combining GM(1,1)-based predictions with GRA-based comparative rankings, we enhance the reliability and strategic value of the analysis.

Keywords:

Grey Prediction, Grey Relational Analysis, Performance, Global Innovation, Market Sophistication

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Forecasting China's thermal power generation using a novel multivariable time-delay grey model

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ABSTRACT

Accurately forecasting thermal power generation is essential for China's sustainable energy planning and green development. This paper proposes a novel multivariable time-delay grey model to forecast China's thermal power generation from 2025 to 2030. The proposed model combines time-delay effects and dummy variables to capture the complex, nonlinear relationships between thermal power generation and economic drivers under limited data conditions. By optimizing parameters with the Aquila Optimizer, the proposed model achieves improved adaptability and forecasting accuracy. The proposed model's fitting MAPE reaches 0.58% and the test MAPE reaches 0.29%, outperforming other comparison models. The forecasting results indicate that China's thermal power generation may grow unstably through 2030. The growth rate may slow due to the increasing integration of renewable energy and carbon neutrality policies. It offers referenceable and foresight insights for the Chinese government to support energy security management and future sustainable development.

Keywords:

Multivariable grey model; Time-delay, Dummy variables; Thermal power generation forecasting

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Forecasting China's thermal power generation using a novel multivariable time-delay grey model

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ABSTRACT

In the consumption of clean energy, wind power consumption has experienced significant growth in recent years. Forecasting changes in its consumption is of critical importance for energy policies and infrastructure planning. Addressing the complexity of wind power consumption trends in recent years, this paper proposes a fractional-order dynamic time delay grey prediction model (FDTGM(1,1)) to forecast China's wind power electricity consumption. This model incorporates linear and nonlinear correction terms and optimizes parameters using the particle swarm algorithm, thereby improving prediction accuracy and adaptability to dynamic data changes. A time-delay function is established to address the issue of time lag caused by external factors in the model. Comparative analysis indicates that the FDTGM(1,1) model outperforms other grey models in prediction accuracy. The model forecasts that China's wind power consumption will increase steadily from 9641.84 PJ in 2024 to 20355.51 PJ in 2030. This study underscores the necessity of strategic infrastructure planning and balanced energy development policies. The findings provide valuable insights for policymakers committed to the sustainable development of the wind power industry. Additionally, they contribute to the advancement of grey prediction models and support strategic planning in the clean energy sector.

Keywords:

Grey prediction model; Wind power consumption; Fractional model; New information priority; Particle swarm optimization

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An improved power-driven grey model for forecasting renewable energy demand

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ABSTRACT

Accurate forecast of renewable energy demand has important significance to energy planning and policy formulation. Nevertheless, the demand of renewable energy is influenced by a variety of uncertain factors, which shows the characteristics of nonlinear and periodic fluctuation. In addition, because of the poor information of renewable energy demand, the traditional forecasting model can not meet the needs of renewable energy demand forecasting. In order to solve the bottleneck of renewable energy demand forecasting, this paper adopts the grey prediction technology which can satisfy the 'poor information and uncertainty' system prediction, and combines the characteristics of energy demand series to propose a novel power-driven grey model based on two-stage decomposition. The model separates the trend component and seasonal component of the modeling sequence by STL decomposition algorithm and HP filter. Then, considering the characteristics of trend component and seasonal component, the new grey power-driven model and Holt-Winters model are established respectively, which adapt to the variation law of trend component and seasonal component. The newly constructed hybrid model is used to forecast the demand of renewable energy in the United States, and the prediction results are compared with some benchmark models. The calculation results present that the proposed model can capture the long-term trend and seasonal fluctuation of time series data better, and more accurate, which is an effective method for dealing with seasonal time series prediction.

Keywords:

Grey model, STL decomposition, HP filter, Renewable energy

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Lithium-ion battery remaining useful life prediction based on a hybrid method of improved GM(1,N) model and Gaussian process regression

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ABSTRACT

Accurately predicting the remaining useful life (RUL) of lithium-ion batteries is crucial for safe operation. Grey prediction models, with advantages in handling small samples and uncertain information, offer a promising approach for RUL prediction. However, most of the existing grey prediction models focus on the degradation trend while neglecting the capacity regeneration phenomenon. To address this limitation, the improved complete ensemble empirical mode decomposition with adaptive noise (ICEEMDAN) is first applied to separate the capacity degradation trend from local regeneration trends, addressing their differences in magnitude and characteristics. A hybrid prediction method, which combines an improved grey multivariate model and Bayesian-optimized Gaussian process regression, is then proposed. For the capacity degradation trend, which exhibits information heterogeneity and an exponential nonlinear trend, a variable new information priority fractional discrete grey multivariate model is proposed for prediction. The model is not only based on the ideas of variable-order accumulation and discrete grey models, but also introduces an additional nonlinear correction term. For the local regeneration trend, which is nonstationary, nonlinear, and noisy, a denoising autoencoder is employed for noise reduction and feature enrichment, followed by the Bayesian-optimized Gaussian process regression model for prediction. Finally, the predictions of each component are reconstructed to obtain the complete capacity sequence. Multidimensional evaluations on multiple NASA battery datasets, including comparisons with common baseline models and ablation studies to verify the effectiveness of each module, demonstrate that the proposed method achieves superior accuracy, stability, and generalization in capacity degradation prediction.

Keywords:

Lithium-ion battery; Remaining useful life; ICEEMDAN; grey multivariate model; Gaussian process regression

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Dynamically-informed conformable fractional discrete GM(1,N) model with probabilistic time-lag response and its application

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ABSTRACT

Discrete grey multivariate models with time lags can effectively characterize systems exhibiting delayed responses; however, they remain limited in extending the accumulative order and modeling the lag term. To address these issues, this study proposes a dynamically-informed conformable fractional discrete grey multivariate model with probabilistic time-lag response, developed through dynamic analysis. First, a conformable fractional order accumulation operator is formulated, drawing on the concept of differential accumulation order, to better account for the systems dynamic variations. Second, a probabilistic response time-lag driving term, based on the Bernoulli distribution, is constructed to represent the uncertain lag effects within the system. Third, both linear and nonlinear correction terms are incorporated into the model structure to exploit the nonlinear characteristics of the data and enhance predictive performance. Additionally, a regularization method is employed for parameter estimation, improving model robustness. The proposed DICFDGM(1, N)-PTL model is applied to analyze port cargo throughput in Jiangsu Province. Experimental results demonstrate that the proposed model outperforms comparable methods in forecasting port throughput and more effectively reveals the lag effects of driving factors on system behavior.

Keywords:

Grey system, grey multivariate model, time-lag effect, discrete grey prediction model, model structure expansion

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