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A summary of grey forecasting and relational models and its applications in marine economics and management

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Abstract

Purpose – Research on grey systems is becoming more sophisticated, and grey relational and prediction analyses are receiving close review worldwide. Particularly, the application of grey systems in marine economics is gaining importance. The purpose of this paper is to summarize and review literature on grey models, providing new directions in their application in the marine economy.

Design/methodology/approach – This paper organized seminal studies on grey systems published by Chinese core journal database – CNKI, Web of Science and Elsevier from 1982 to 2018. After searching the aforementioned database for the said duration, the authors used the CiteSpace visualization tools to analyze them.

Findings – The authors sorted the studies according to their countries/regions, institutions, keywords and categories using the CiteSpace tool; analyzed current research characteristics on grey models; and discussed their possible applications in marine businesses, economy, scientific research and education, marine environment and disasters. Finally, the authors pointed out the development trend of grey models.

Originality/value – Although researches are combining grey theory with fractals, neural networks, fuzzy theory and other methods, the applications, in terms of scope, have still not met the demand. With the increasingly in-depth research in marine economics and management, international marine economic research has entered a new period of development. Grey theory will certainly attract scholars' attention, and its role in marine economy and management will gain considerable significance.

Keywords Grey system theory, CiteSpace, Grey forecasting and relational models, Marine economy

Paper type Literature review

1. Introduction of the grey theory

In 1982, "Systems & control letters" issued by the North Holland Publishing Company published the first grey system paper "The control problems of grey systems" by professor Deng, a Chinese scholar (Deng, 1982). In the same year, the Journal of Huazhong University of Technology published professor Deng's first grey system paper "grey control system" in Chinese (Deng, 1982). The publication of these two pioneering articles marked the beginning of grey system theory which is a new topic. As a new method aiming to solve problems involving small-size data and limited data, the grey system theory uses a system of uncertainty (e.g. "the data is partially known and partially unknown," "limited data") as the research object. The grey system method applies mainly data mining on the "part" of known data, to extract valuable information, to achieve a correct description of the system operation and evolution laws, and, thus, we can oversee the system efficiently. The grey relational models and grey prediction models are two main branches of the grey systems. The grey prediction models include single variable grey prediction models and multivariable grey prediction models. After many improvements, the theory of grey system has been well developed and widely used in many areas.

1.1 The review of grey relational analysis

Grey relational analysis is one of the main components of the grey system theory. The basic idea is to calculate the relation based on the similarity of data series representing the characteristics of systems. Deng first proposed the concept of grey regional degree in the grey relational theory. The purpose was to test the effect of the prediction model, which was Deng's initial intention of constructing the regional degree. Later, based on Deng's relational degree, various extension models and modeling mechanisms from different perspectives are proposed. The grey relational theory has been widely applied in the economic, social, industrial, agricultural, transportation, education, medical, ecological, water conservancy, aero-spatial and other fields since it has become well developed. The applications solved many uncertainty problems, e.g., "small sample and poor quality data," in these areas, and the grey relational theory has become one of the branches of grey system theory with the most extensive application and the most achievements.

In view of the important use of the grey relational analysis, after professor Deng first proposed Deng's relational degree in 1982, scholars around the world continually proposed and improved many new quantitative models involving the grey relational degree from perspectives of proximity and similarity (Wang, 1989; Wang and Zhao, 1999; Mei, 1992; Dang, 1994; Tang, 1995; Sun and Dang, 2008; Shi *et al.*, 2008; Shi *et al.*, 2010), and studied the fundamental characteristics of the grey relational degree (Xie and Liu, 2007; Cui *et al.*, 2009). To measure the relation of the data series more comprehensively, as well as the proximity and similarity of the changes between the series, Liu *et al.* constructed a grey regional model to measure the relation and effects between two data series from the perspectives of similarity and proximity based on the grey absolute regional model (Liu *et al.*, 2010). The development of grey relational analysis has been greatly promoted by the continuous proposals of new grey relational models. These models reflect the degree of relation among various factors in a system from different perspectives. The models have no special requirements for data distribution and quantity, and are easy for calculation. They have been applied in the research and practice of the economic society to different degrees.

Due to limitations of the above grey relational models that can only be applied in single-indexed data series, many researchers now turn to panel data. As a synthesis of cross-section data and time series data, it can overcome the multicollinearity of time series and have richer information connotation. Presently, more and more researchers use panel data for grey relational analysis. Zhang proposed an extended grey absolute relational model based on spatial distance and double integrals, which filled in the gap of the application of grey relational theory using panel data (and extended the application scope) (Zhang and Liu, 2010). Then, Qian introduced the "horizontal" distance, "incremental" distance, and "variation" distance into the calculation of the grey relational degree and constructed the grey matrix relational model with the help of Deng's grey relational degree (Qian *et al.*, 2013). Wu used the second-order difference quotient approximation to replace the second-order derivative and defined the convexity in three-dimension by using the Hessian matrix, and, then, proposed a clustering method for panel data based on the grey convex relational degree (Wu and Liu, 2013). Liu used a grid method to describe the geometric characteristics of panel data in three-dimension and constructed a grey grid relational model with the help of slope relational degree (Liu *et al.*, 2014). Liu *et al.* (2014) proposed a grey clustering analysis based on grey accumulation generation relational analysis, which was used to determine the hierarchical structure of clusters using panel data (Li *et al.*, 2015). Cui used the development speed index and growth speed index to measure the similarity between a correlation factor matrix and a system characteristic behavior matrix from the individual and time dimensions, and constructed the grey matrix similarity correlation model using panel data (XXX, 2015). Wu used panel data as a spatial vector series, constructed the similarity grey relational model with vectors' angles, and constructed the proximity grey relational model based on vector differences (Wu *et al.*, 2016). Dang introduced grey entropy and proposed a testing model for grey relational clustering (Dang *et al.*, 2017).

In sum, the grey relational model mainly analyzes the relation through geometric features such as slope, area, and distance, and expands continuously to three-dimensional modeling. Its development is to reflect the degree of relation between objects more truly and comprehensively.

1.2 Review of the GM (1,1) model

The GM (1,1) is an important prediction model proposed by professor Deng in the 1980s to solve the uncertainty problem of "small sample size" and "poor information quality" (Deng, 1985). Since the introduction of the GM (1,1) model, many scholars have carried out a lot of research on it. They have focused mainly on these four aspects of the GM (1,1) model (Chen, 1988; Dang *et al.*, 2005): initial conditions, preset values (Tan, 2000a, b, c), model parameters (He and Song, 2005) and residual correction (Li and Kou, 2018), improving the prediction accuracy of the model. Due to the accuracy and simplicity of the GM (1,1) model prediction, scholars have proposed many novel versions of the GM (1,1) model. To eliminate the index fitting error, Xie *et al.* (Xie and Liu, 2009) proposed a discrete model DGM (1,1). To eliminate the error caused by the traditional grey Verhulst model jumping directly from the differential equation to the difference equation, Cui *et al.* (2010) proposed a grey dispersion Verhulst model. Dai (Dai and Li, 2005) proposed a non-equal spacing GM (1,1) model to solve problems such as data inadequacy, strongly beating data, and non-equal interval series. Akay (Away and Atak, 2007) considered the updating of data, and removed old information in time while continuously adding new information. The metabolic GM (1,1) model is proposed to reflect the current characteristics of the system better and reveal the development trend of the system better. After decomposing the binary orthogonal wavelets to non-stationary time series and separating low frequency wavelets, Zhang *et al.* (Zhang and Ren, 2010) applied the GM (1,1) model and proposed a non-stationary time series prediction method based on wavelet decomposition and residual GM (1,1)-AR, which realized accurate prediction of time series with mean non-stationary characteristics. Chen *et al.* (Chen and Gan, 2016) proposed an improved method of grey waveform prediction model for time series with irregular amplitude. Considering seasonal factors, Xiao and Wang (Xiao *et al.*, 2017; Wang *et al.*, 2018), respectively proposed a seasonal grey prediction model SGM (1,1) and seasonal rolling grey prediction model. Some scholars have introduced the neural network, particle swarm optimization, convolution integral and others into the GM (1,1) model to solve parameter optimization problems (Tien, 2009; Zou *et al.*, 2007; Zhou *et al.*, 2002; Chen and Pai, 2015). The GM (1,1) power model (Wang, 2007; Wang *et al.*, 2010; Wang, 2013) is a new grey prediction model developed in recent years in which the power index contained in the grey action quantity in the model can flexibly determine the specific form of the model. Wei proposed a general univariate prediction model GGM (1,1) based on the GM (1,1) and DGM (1,1) models, overcoming the shortcomings of the GM (1,1) and the DGM (1,1) models. Additionally, many scholars have done a lot of research on data accumulation, including reciprocal accumulation (Yang and Zhang, 2003), reverse accumulation (Song and Deng, 2001), new information priority accumulation (Zhou *et al.*, 2017), generalized accumulation (Huang and Xiang, 2009) and fractional order accumulation (Wu *et al.*, 2014, 2018). The GM (1,1) model solves a large number of practical problems in the fields of production, life, science and technology, and its application scope extends to various fields such as finance, medicine, environment, design, energy, military and sports. In summary, the model has great practicality and accuracy.

1.3 Review of the grey multivariate prediction models

The GM (1,1) model mainly predicts and analyzes a single time series. However, the systems in real economic society are usually influenced by multi-factors and multivariable complex systems. In that case, the GM (1,1) model is not able to exert its advantages. Therefore, Deng proposed the GM (1, N) model, to analyze and predict a system with multi-variables (Deng, 1990).

To improve the prediction accuracy of the GM (1, N) model, many scholars have studied the properties of the model and proposed many optimized GM (1, N) models, making the GM (1, N) model well developed. On the basis of the traditional GM (1, N) model, many scholars have studied the mechanism of the grey multivariate model's driving variables (Yin and Luo, 1999; Zhang, 2014; Zhang *et al.*, 2015). Ding proposed a TGM (1, N) optimization model with a trend of driving variables (Ding *et al.*, 2015). Wang inserted parameters between the preset values of the driving variables. The preset values of the model were optimized, and the OGMC (1, N) model based on the optimized values was constructed (WANG and HAO, 2016). Additionally, many scholars have studied the problem of inaccurate response time formula and low accuracy of GM (1, N) models (Qiu and Liu, 2006; Zhou and Fang, 2010; He and Wang, 2013; He, 1997; Peng, 2016). Ma (2018) combined the grey model with machine learning and other related methods, which improved greatly the accuracy of the model. Wang and Ding studied the interaction between variables; and predicted the R&D input and output of large- and medium-sized high-tech companies in China, as well as the output of high-tech industries in Jiangsu Province (Wang, 2017; Ding *et al.*, 2018). To reflect the time lag phenomenon in the real economic society, Zhai first established the GM (1, 2) model based on time-delay parameters (Geng *et al.*, 1996). Since then, scholars have proposed a number of improved models (Hao *et al.*, 2011; Huang, 2009; Mao *et al.*, 2015). Wang introduced the driving term delay coefficient to reflect the influence of different period's data on the system behavior and obtained the derived time-delay GM (1, N) model (Wang, 2015). Ding *et al.* (2017) introduced a lag coefficient control driving term and proposed a multivariate discrete grey prediction model considering the cumulative effect of time delay. Ma *et al.* used a new time-varying multivariate grey model to predict China's natural gas consumption (Ma and Liu, 2017).

Due to the convenience and good performance of multivariate prediction, many scholars have proposed new multivariate prediction models, for example, the grey model with convolution integrals, abbreviated as GMC (1, n). It has high accuracy of prediction using the data that are put into the system, while the GM (1, N) does not. The GMC (1, n) model with optimized parameters and their extensions include the grey dynamic model with convolution integrals is put forward, abbreviated as DGDMC (1, n) (Tien, 2009). The interval grey dynamic model with convolution integrals, abbreviated as IGDMC (1, n) (Tien, 2008) and the first-pair-of-data GMC (1, n), abbreviated as FGMC (1, n) (Tien, 2011; He *et al.*, 2015; Wang and Hao, 2016) are established. Wang proposed the grey multivariable GM (1, N) model and its derived model, and verified the effectiveness of the new model through numerical simulation and application examples (Wang, 2014). The major errors of the simulation and prediction were caused by the difference of the model itself. Xie and Liu proposed a discrete multivariate grey model (Xie and Liu, 2006, b, 2008, 2009). To represent the interaction between the driving variables, Zhai *et al.* proposed the MGM (1, m) model (Geng *et al.*, 1997), and many scholars have made corresponding improvements (Li *et al.*, 2003, 2007; Cui *et al.*, 2008). In addition, Xiong first studied the multiplicative transformation characteristics of the MGM (1, m) model, and then improved the preset value of the MGM (1, m) model to improve the prediction accuracy of the model. Finally, a multivariable non-equal interval MGM (1, m) model was constructed for non-equidistant data series (Xiong, Dang and Zhu, 2011; Xiong, Dang and Wang, 2011; Xiong *et al.*, 2012). Multivariate grey prediction models have been widely used in the integrated circuit industry, environment, biomedicine, finance, engineering, high-tech industries, transportation, industry, tourism, energy and other fields. The multivariate grey prediction model is becoming more and more sophisticated, and the practicability and effectiveness of the method are worthy of further study.

1.4 Summary of the grey model literature

In summary, since the beginning of the grey system theory, the research results have increased year by year. The development of the two branches of grey relation and grey prediction have gradually developed and has been successfully applied in various fields, but the literature on their applications in the marine field is rare. However, due to the lack and inconsistency of marine data, along with the complexity of the ocean itself, it is difficult to overcome these characteristics of the ocean by methods that are already studied on the ocean. On the contrary, the grey system method is appropriate. The method for small samples is ideal for marine systems where data is inadequate. The above analysis shows that, in recent years, the grey model has had many research objects and a wide range of research methods. However, there are still few articles summarizing the research progress of the relevant literature, the new studies, and the application of grey system methods in emerging fields related to the ocean. To understand the related methods, this paper introduced the research progress, theory and method system of grey method in detail, and used bibliometrics analysis to quantitatively analyze the results, and intuitively displayed the research status quo by means of literature mapping. Our research result provides a new way to apply the grey method to new and popular topics in the marine field. The remainder of this paper is organized as follows. The second part analyzes previous research results, development trends and main research fields of the grey model. The third part uses bibliometrics analysis to analyze the research status quo of the grey theory. The fourth part describes the application of the grey methods in the marine economy and future research directions. The fifth part summarizes the paper.

2. Statistical analysis of articles published on grey models

This section mainly carries out statistical analysis to published articles on the grey system theory. We aim at analyzing articles from journals in CNKI, Web of Science, Elsevier from 1982 to 2018. To emphasize the research quality, we choose Chinese articles only from core journals in CNKI, not from meetings or theses. The keywords searching, using "grey relation," "GM (1,1)," and "multivariate grey prediction model" and others, presents us with the following results (Figure 1).

Table I shows that articles from 1982 to 2018 on grey cumulative statistics include three branches: grey relation, GM (1,1) prediction model and multivariate grey prediction model. Grey model articles' number increases year by year. By 2018, more than 14,622 articles were published in significant journals worldwide; there were 11,510 articles in Chinese and 3,112 articles in English. The theory of grey system attracted

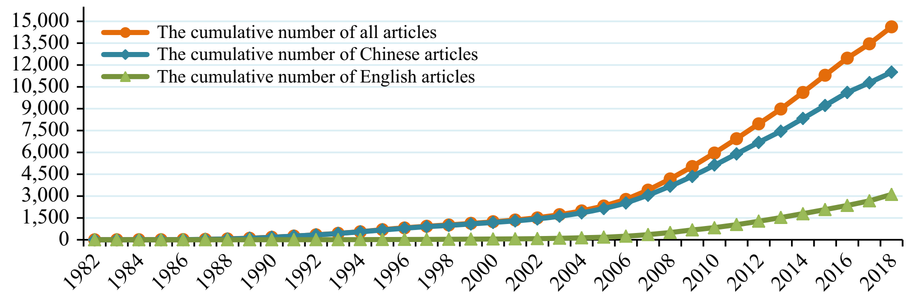

Figure 1. The cumulative number of articles year by year

the interest of a large number of scholars, and a lot of studies carried out including the study of model properties, the improvement of model methods and the establishment of new models.

2.1 Languages of the articles

A total of 10,223 articles were written about grey relational analysis, in which 8,181 articles were in Chinese and 2,042 articles were in English. Among the 4,209 articles about grey prediction models, 3,820 articles were on GM (1,1) prediction model and only 389 articles were on grey multivariate prediction model. The number of studies in Chinese far exceeded that in English. Articles related to grey relation accounted for 70.84 percent of the literature, followed by GM (1,1) prediction model and grey multivariable prediction model.

2.2 Annual trends of the articles on grey system theory

Table II shows the publication year of GRA and grey prediction models in Chinese. Since 1982, the research on grey models has been increasing popular. Among them, the number of GRA studies has been increasing year by year, with a slight decline since 2016. However, it can still indicate that the grey relational models have become a method that has attracted much attention worldwide. The number of studies on grey prediction models is less than that in grey relational models; however, it also increases year by year. In 2016, the number of studies decreased a little, but it began to rise slightly in 2017. In general, the research

Table I. Language of articles in GRA and grey prediction models

	Grey relational analysis	GM (1,1) prediction model	Grey multivariate prediction model	Grey prediction record counts
Chinese	8,181	2,835	309	3,144
English	2,042	985	80	1,065
Total	10,223	3,820	389	4,209
Proportion (%)	70.84	26.47	2.70	29.16

Table II. Application areas of Chinese literatures

Gray model	Application areas	Record counts
Grey prediction model	Economy	434
	Society	400
	Management science	289
	Energy	284
	Environment	277
	Biological science	265
	Industry	236
	Traffic	234
	Agriculture	194
	Marine areas	101
Grey relational analysis	Engineering	174
	Economy	168
	Quantitative economics	165
	Agricultural economy	132
	Environment	116
	Computer science	90
	Management science	73
	Energy	69
	Industrial economy	62
	Traffic	51

spectrum of grey prediction models is very wide and it has always been popular among scholars (Figure 2).

Table III shows the publication year of GRA and grey prediction models in English. The grey relational model and grey prediction model have been studied since 1989. Since then, articles about grey relation and grey prediction have been published in journals with high international impacts. The grey system has gradually caught much attention from a large number of scholars and they conducted in-depth research. It can be seen that the number of articles published in international journals on both grey relational model and grey prediction model is increasing year by year, showing an increasing trend. Among them, the number of articles on GRA decreased only slightly in 2010, and the increasing trend was obvious from 2011 to 2012 and from 2017 to 2018, indicating that the research on GRA did not lose popularity in recent years. The grey prediction model began to show a slow growth from 2010 and showed a slight upward trend from 2016 to 2018 (Figure 3).

2.3 Grey model studies by areas

Based on CNKI core journals, China's 3,144 articles were on grey prediction models, 8,181 articles on grey relational models, and 1,065 article on the grey prediction models.

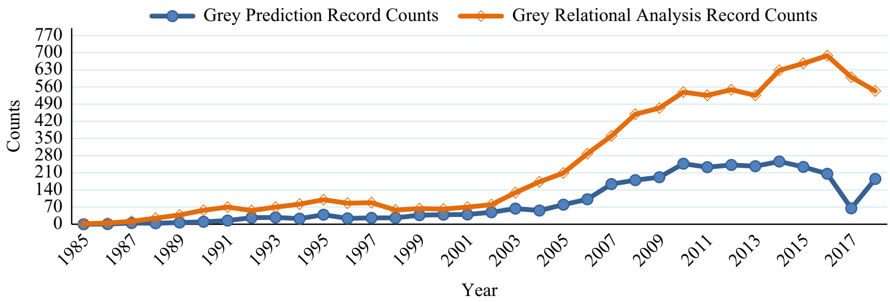

Figure 2. The statistics of publication year of Chinese literature on grey models

Grey model	Application areas	Record counts
Grey prediction model	Energy	165
	Environment	141
	Technological development	109
	Economy	85
	Computer science	70
	Engineering	67
	Management science	60
	Marine areas	41
	Medical science	40
	Traffic	30
Grey relational analysis	Engineering	987
	Materials science	326
	Computer science	309
	Mathematics	227
	Environmental sciences ecology	218
	Automation control systems	161
	Energy	134
	Management science	128
	Technological development	123
	Chemistry	66

Table III. Application areas of English literatures

In English literature, 2,042 articles were on grey relational models from Web of Science and Elsevier. These articles are subject in the field of statistical classification screening, in Chinese and English literature statistics of the top ten hot spot of research. Tables II and III are statistics of the top ten research fields under the classification. It can be seen that the study of the grey model involves many subject fields, and it is an applied discipline and interdisciplinary subject that is used widely. Economics and sociology are the most common subject fields in the study of grey prediction. There are 2,714 Chinese articles on grey prediction and 1,100 on grey relation in Table II. The most studied areas of grey prediction are economics and sociology, with 434 articles on economics and 400 articles on sociology, followed by other disciplines. In addition to economics and sociology, management, energy, environment, biological science, industry, transportation and agriculture are the most common application fields in grey prediction research. There are also emerging areas of the marine field, which have been studied in recent years, and the research on grey prediction in the field has gradually increased. The research field of grey relation is very extensive, and it involves almost all fields. Therefore, when categorized and aggregated the number is small; however, it can still be seen that engineering, economics, and quantitative economics are the most studied areas of grey relation. The number of articles has reached 174, 168 and 165. Grey relation is also applied in the fields of agricultural economy, environment, computer science, management, energy, industrial economy and transportation. It can be seen that economics, management, environment, industry, agriculture, transportation and energy are common application areas of Chinese literature on grey relation and grey prediction.

Table III summarizes the top ten research areas under the classification, including 808 English articles on grey prediction models and 2,679 English articles on grey relations. As Table III shows, energy and environment are the most studied areas of grey prediction. The number of articles on energy reached 165, and the number of articles on the environment reached 141, followed by other subject areas. In addition to energy, environment, technology development, economics, computer science, engineering, management, oceanography, medicine and transportation are the most common application areas in grey prediction research. The research field of grey relation is very extensive. It can be seen that engineering is the most applied field of grey relation, and the number of articles has reached 987. In addition, materials science and computer science are also popular topics in research, and the number of articles has reached 326 and 309, respectively. Grey relation is also used in mathematics, environmental science, automatic control disciplines, energy, management science, science and technology and chemistry. It can be seen that energy, environment, science and technology, computer science, engineering and management science are common application areas of English literature on grey relation and grey prediction.

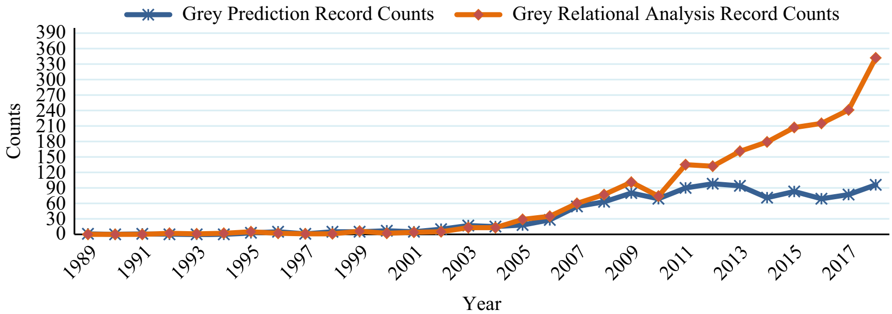

Figure 3.
The statistics of publication year of English literature on grey models

3. Research status quo regarding grey models based on CiteSpace

The data samples in this section are only taken from the Web of Science core collection database from 1982 to 2018, and search keywords are "grey association" and "grey prediction," get 2,515 articles. We use the CiteSpace software to extract the country, institutions, authors, keywords and fields from the above documents to conduct statistical analysis, generating maps of origin countries, institutions, authors, keywords and fields.

3.1 Geographic origins of the grey model studies

According to the collected data of 1,649 articles on grey relation and 866 articles on grey prediction, the country (region) origin of the authors was read and summarized. In total, 34 countries and regions and 24 countries were selected for grey relation and grey prediction, respectively. As Figures 4 and 5 show the results were relationship networks among the countries.

In Figures 4 and 5, the node represents a country or region. The size of the node depends on the number of grey relation and grey prediction articles published in the country. The more the number published in the region, the larger the node. China has the largest node in Figures 4 and 5, indicating that China has published the largest number of articles on grey

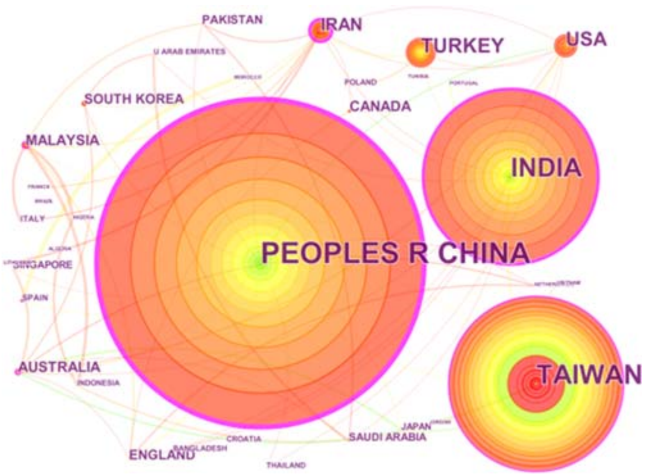

Figure 4. Network of cooperation among 34 countries and regions on grey relational studies

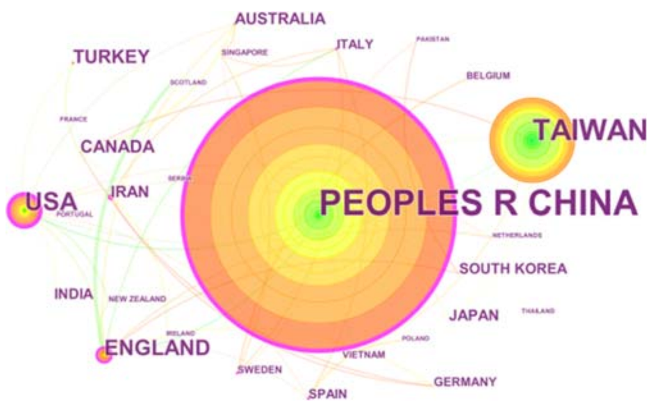

Figure 5. Network of cooperation among 24 countries and regions of grey prediction studies

relation and grey prediction. The connection between nodes represents the cooperation relationship between two countries or regions, and the density of the network indicates the closeness of cooperation among scholars in various countries or regions. Generally speaking, the greater the density of the network, the closer the cooperation among scholars who study grey relation in various countries or regions. Figures 4 and 5 show that the connections between the nodes are not dense, indicating that the cooperation between countries or regions is not frequent.

We can see that at the center of each of the top 10 countries or regions, the cooperation frequency is higher in Table IV. The data are based on the country or region in which the author is located. The higher the frequency, the more times they have collaborated. It is known from Table IV that China, Taiwan and the USA have more research on grey relation, and there are more studies on grey prediction in China and Taiwan. In short, scholars from China and Taiwan have the most studies on grey system models, leading the majority of scholars on the in-depth study of grey methods and models.

3.2 Grey model studies by institutions

To understand the distribution of research institutions better, we respectively established relation networks between the research institutions for grey relation and grey prediction, as shown in Figures 6 and 7.

In Figures 6 and 7, the nodes represent research institutions, and the size of a node depends on the number of grey relation and grey prediction articles published by an institution. The more the number of publications, the larger the node. In Figure 6, National Taiwan University of Science and Technology has the largest node, indicating that the institution publishes the most articles in the grey-related areas. In Figure 7, Nanjing Aerospace University has the largest node; its researchers have published the most articles on grey system research. The connection between the nodes indicates cooperation relationships between institutions. The greater the network density, the closer the collaboration between institutions, and the academic exchange is stronger. Figures 6 and 7 show that there are many institutions that study grey relation and grey prediction worldwide, and the communication between institutions is relatively intense.

Table V shows that at the center of the top 10 institutions, the frequency is higher. The data are based on the statistics from the research institutions. The higher the frequency, the more times they have collaborated. The higher the value at the center, the more concentrated the study topics. Table V shows that the National Taiwan University of Science and Technology, the National Institute of Technology, and the Nanjing Aerospace University have more researches on grey relation. Nanjing Aerospace University and North China Electric Power University have more researches on grey prediction. In short, Nanjing

Table IV.
Top 10 countries and regions on the grey model study

	Grey relational model			Grey prediction model		
Rank	Countries and regions	Frequency	Centrality	Countries and regions	Frequency	Centrality
1	China	670	0.46	China	612	0.97
2	Taiwan	368	0.17	Taiwan	224	0.07
3	India	357	0.39	USA	88	0.52
4	Turkey	78	0.01	England	45	0.5
5	USA	63	0.09	Turkey	22	0
6	Iran	46	0.34	Canada	15	0.05
7	Australia	22	0.11	Australia	14	0
8	Malaysia	22	0.15	Iran	14	0.02
9	Canada	20	0	Japan	10	0
10	England	18	0.04	South Korea	10	0.02

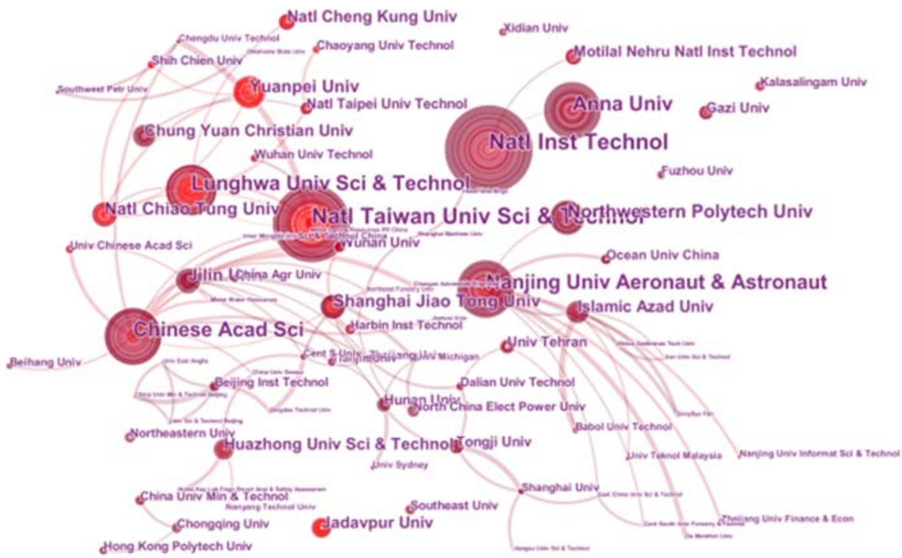

Figure 6.
Network of cooperation between institutions of grey relational literatures

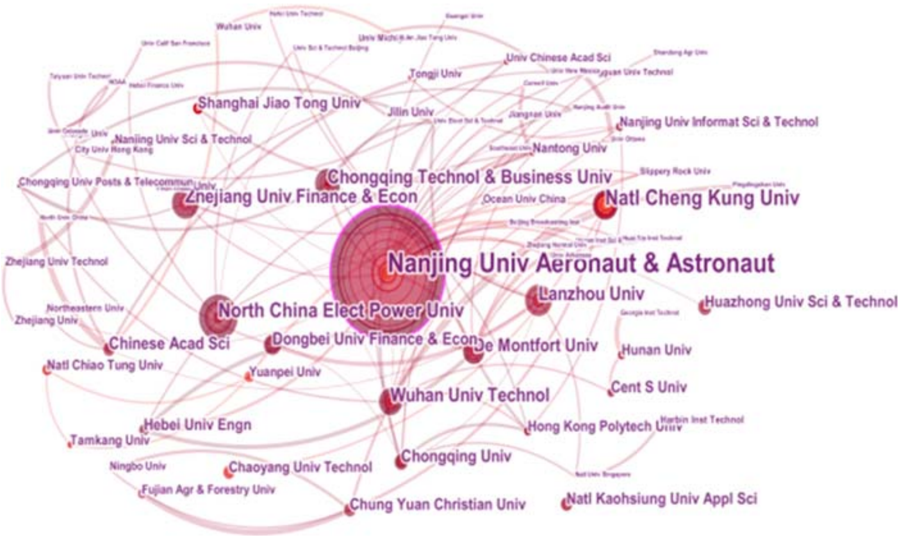

Figure 7.
Network of cooperation between institutions of grey prediction literatures

Aerospace University is the pioneer of both grey relation and grey prediction studies. The grey system research represented by this institution drives deep cooperation and exchanges with other research institutions.

3.3 Analysis of keywords on grey models

In this paper, we have searched 1,649 grey relation and 866 grey predictions articles from the Web of Science database. The CiteSpace software extracts keywords from the above documents and generates keywords maps, as shown in Figures 8 and 9.

Model	Rank	Institutions	Frequency	Centrality
Grey relational analysis	1	National Taiwan University of Science and Technology	52	0.01
	2	National Institute of Technology	51	0.01
	3	Nanjing University of Aeronautics and Astronautics	38	0.02
	4	University of Chinese Academy of Sciences	38	0.06
	5	Luangwa University of Science and Technology	37	0.02
	6	Anna University	36	0.01
	7	Northwestern Polytechnic University	23	0
	8	Shanghai Jiao Tong University	21	0.01
	9	Yampi University	21	0.01
	10	Jilin University	19	0.02
Grey prediction model	1	Nanjing University of Aeronautics and Astronautics	79	0.1
	2	North China Electric Power University	27	0.03
	3	National Cheng Kung University	22	0.01
	4	Lanzhou University	21	0.06
	5	Wuhan University of Technology	19	0.01
	6	Zhejiang University of Finance and Economics	19	0.01
	7	Chongqing Technology and Business University	19	0.04
	8	De Montfort University	17	0
	9	Chongqing University	13	0.05
	10	Dongbei University of Finance and Economics	13	0.02

Table V.
Top 10 Institutions on the grey system study

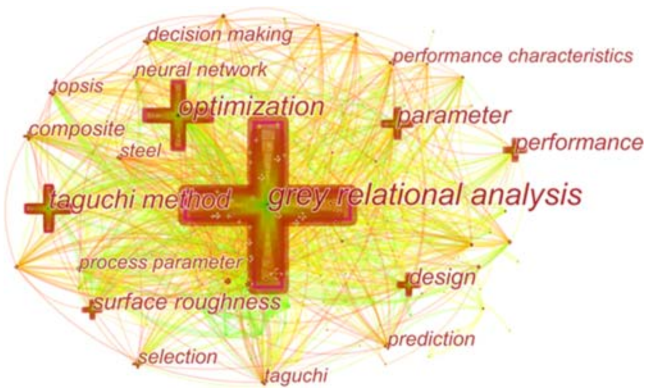

Figure 8.
The keywords map of grey relational literature

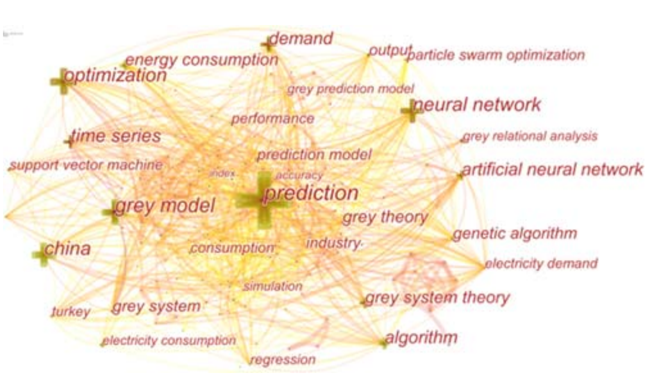

Figure 9.
The keywords map of grey perdition literature

From the perspective of information theory, the higher the centrality and frequency of keywords, the more concentrated the attention of international scholars paid to the area of study for a period of time. The area of study is grey relation and grey prediction. The centrality of keywords is calculated by the keywords that have appeared in the literature which is searched on Web of Science. If it is more than 0.1, it is strong. Many studies have been carried out using these keywords and have a strong influence. Therefore, this paper screens out popular keywords with high centrality and frequency. Table VI shows the centrality and frequency.

As Figures 8 and 9 and Table VI show the structural features of the grey study keywords are as follows.

From the centrality analysis of the nodes, after removing high-frequency keywords, i.e., “grey relational analysis” (0.21), “neural network” (0.13), “optimization” (0.12), “taguchi method” (0.12), these are the high-quality keywords (centered in brackets, same for the rest of the paper). This means that “neural network,” “optimization,” and “taguchi method” are the words with the largest impacts except for the term “grey relational analysis.” In addition, “model” (0.1), “performance” (0.07) and “surface roughness” (0.07) are also the keywords with higher centrality rankings. There are many studies carried out using these keywords, which have some influence.

From the analysis of the frequency through the size of the nodes, “grey relational analysis” is still the most frequent keyword except for the topical vocabulary, which appears 725 times. In addition, “optimization,” “taguchi method,” “model,” “parameter,” “system,” and “neural network” are also keywords with high frequency. Combined with the centrality analysis of the nodes, grey system research is closely related to “taguchi method,” “neural network,” “model,” “optimization,” also the popular areas of grey relational research.

From the centrality analysis of the grey prediction nodes, after removing the topic high-frequency keyword “prediction” (0.19), “grey model“ (0.16), “demand” (0.12) and “neural network” (0.11) are highly central keywords(centered in brackets, the same below). This means that, except for keywords such as “prediction,” “grey model,” “demand,” and “neural network” are the most influential words. In addition, “algorithm” (0.08), “optimization” (0.07), and “China” (0.07) are the top keywords in the centrality ranking. The research conducted using these keywords has some influence.

From the analysis of the frequency through the size of the nodes, “prediction” is still the most frequent keyword (except for being used as a topic name), which has appeared 413 times. In addition, “grey model,” “neural network,” “system,” “optimization,” “system,” “China” are keywords with high frequency. Combined with the centrality analysis of the nodes, the grey research is related closely to “grey model,” “neural network” and “optimization,” also the latest areas of grey prediction research.

	Grey relational model			Grey prediction model		
Rank	Keywords	Frequency	Centrality	Keywords	Frequency	Centrality
1	Grey relational analysis	725	0.21	Prediction	413	0.19
2	Optimization	335	0.12	Grey model	357	0.16
3	Taguchi method	246	0.12	Neural network	163	0.11
4	Model	171	0.1	System	145	0.05
5	Parameter	168	0.04	Optimization	101	0.07
6	System	167	0.07	China	90	0.07
7	Neural network	147	0.13	Time series	74	0.06
8	Design	130	0.05	Gray prediction	65	0.08
9	Performance	126	0.07	Demand	65	0.12
10	Surface roughness	112	0.07	Algorithm	65	0.08

Table VI. Top 10 keywords searched on the grey system study

In summary, it can be seen that the research on the grey model focuses mainly on model optimization and determining of parameters. The popular topics in grey relation and grey prediction are related closely to neural networks.

3.4 The categories in grey system literature

Many fields are involved in the study of grey system theory. To understand the hot topics and fields of the grey model research better, we categorized 1,649 grey relational studies and 866 grey prediction studies from the Web of Science database. A map of the literature classification is established, as shown in Figures 10 and 11.

The more the number of occurrences of a subject in which the document belongs, the larger the node in the map. The color of the node represents the year of publication. The lighter the color the near the publication year. There are 93 nodes in Figure 10, and there are 85 nodes in Figure 11. The node labels represent the subject of the literature; the diameter of the node is positively correlated with the number of articles in the subject. The thickness reflects the strength of the cooperative relationship between the two. The periphery of some center nodes is surrounded by a purple node, indicating that the center node has extensive connections with nodes in other research fields. Such nodes are often hubs in the discipline or knowledge domain that has special significance in the node network.

From Figures 10 and 11, it is found that the grey system theory research involves many subject areas, and it is a relatively widely used and interdisciplinary subject. A larger circle

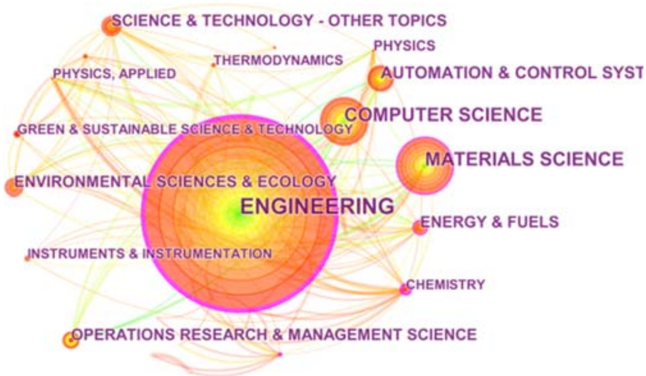

Figure 10.
The categories in the grey relational literature

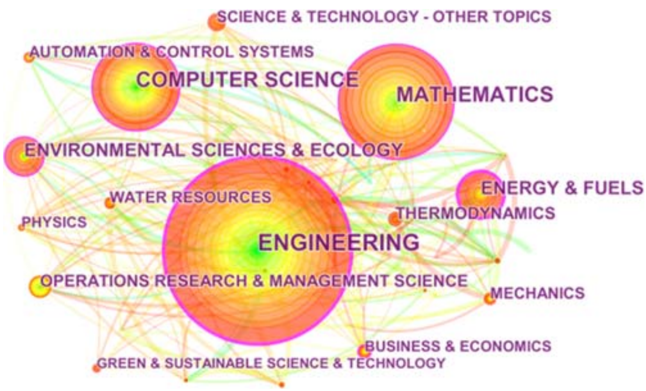

Figure 11.
The categories in the grey prediction literature

in the figures indicates that the subject has a higher frequency of citations, and the denser points indicate that the subjects are more central. Figure 10 and Table VII show that the largest node in the figure is engineering, ranked first with a frequency of 1,579. The annual ring of the node shows that the thickness of the ring increases gradually, indicating that the frequency increases gradually with time. The periphery is surrounded by a purple node, indicating that this node is a critical node, and it plays an important role in the entire grey relation method and connects with other disciplines. It indicates that the grey relational model is related most closely to engineering, followed by materials science, computer science, mathematics, etc. The grey relation method is also applied in many fields such as environmental sciences and ecology, energy and fuels, and automation and control systems.

Figure 11 and Table VII show that the largest node in the figure is engineering, with a frequency of 766. From the annual ring of the node, the thickness of the annual ring is increased gradually, indicating that the number of citations has increased gradually over time. Grey prediction is most closely related to engineering, followed by mathematics, computer science, environmental sciences and ecology, energy and fuels and other fields.

In addition, the node of the grey relation and grey prediction of engineering are both surrounded by purple nodes, indicating that these two nodes are their critical nodes, and engineering is a hot topic for grey system research. As Table VII shows, both the grey relation and the grey prediction are closely related to disciplines such as engineering, computer science, mathematics, environmental sciences and ecology, energy and fuels, and automation and control systems.

4. The application of grey theory in marine economic research

In the era of increasing global population and decreasing land energy and mineral resource reserves, the marine economy has become a new area for economic competition among various countries. The major marine industries maintain rapid growth, and the marine economic development in coastal areas has its own characteristics. However, at the same time, rapid development also faces many bottleneck problems such as the lack of data available in marine economic research. Professor Deng Julong's grey system theory can handle small

Model	Rank	Category	Frequency	Centrality
Grey relational model	1	Engineering	1,579	0.68
	2	Materials science	475	0.2
	3	Computer science	459	0.19
	4	Mathematics	407	0.18
	5	Environmental sciences and ecology	210	0.23
	6	Energy and fuels	175	0.23
	7	Automation and control systems	141	0.15
	8	Operations research and management science	113	0.05
	9	Science and technology – other topics	102	0.05
	10	Physics	100	0.04
Grey prediction model	1	Engineering	766	0.31
	2	Mathematics	487	0.19
	3	Computer science	308	0.18
	4	Environmental sciences and ecology	214	0.12
	5	Energy and fuels	113	0.23
	6	Operations research and management science	65	0.01
	7	Thermodynamics	56	0.01
	8	Business and economics	51	0.1
	9	Water resources	48	0.03
	10	Automation and control systems	45	0.02

Table VII. Top 10 categories of the grey system literature samples, few data, and poor information quality, which can solve marine economic research problems to some extent. Yin Kedong *et al.* (Bai and Zhou, 2015; Kedong and Yangeet, 2005; Kedong *et al.*, 2007; Ke-dong and Zi-qiang, 2009) applied the grey system theory to the study of marine economy for the first time. Subsequently, it defined the connotation and extension of the concept of marine recycling economy, systematically proposed the evaluation index system of marine recycling economy, and, then, applied the grey relation analysis. The theory has been used to analyze quantitatively the related effects of land and marine economic development. At the international level outside China, there are relatively few studies on marine economy using grey system theory. Liu D *et al.* (Liu *et al.*, 2000) used the earliest grey system theory and Markov theory to predict the level of flood peaks and applied to economic evaluation and risk analysis. Wang SM *et al.* (Wang and Chung, 2007) used the GM (1,1) prediction model, combined with regression analysis and time series to predict the number of seafarers needed, and provided a reference for the establishment of manpower policies of Marine Corps officers related to government agencies. L (Lee *et al.*, 2012) used grey relational analysis to rank companies after the financial crisis and analyzed the status of international trade between South Korea and Taiwan. In the initial stage of the study, the study of the marine economy using the grey system theory was relatively broad in scope and later turned to specific areas of the marine economy.

4.1 Research on major marine industries based on grey models

The marine industry is an important area in the field of marine economic research. It involves the efficiency of marine economic development. In the marine industry, Zhao *et al.* (Wei and Ting, 2009) and Xu *et al.* (Sheng and Xin, 2012) used the grey prediction, the index prediction method, and the grey relation analysis method to analyze and predict the development trend of the marine industry and the marine industrial clusters. Finally, they came to the conclusion that the three industries are unbalanced and proposed corresponding measures. In an era when the marine economy has gradually become a strong support for the economic development of the coastal areas, the marine economy continues to maintain a good momentum of development. The traditional marine industries have been upgraded continuously, and the emerging marine industries have quickly started to become the focus of economic transformation.

4.1.1 The application of grey methods in marine fisheries. Marine fishery is a pillar industry of marine traditional industries. Zhang (Weiqiang, 1988) first established a grey dynamic model to predict fishery production. Zhou *et al.* (Yuanjian and Zeliang, 1994) made recent predictions of marine fishery production in China by establishing GM (1,1) models for sea catch and sea catch production. They put forward measures and methods to promote the growth of marine fishery production, and provided scientific basis for the fishery production department to formulate investment decisions and rationally arrange production. Chen (Xinjun and Yingbiao, 2001) and Yin (Yin, 2009) used the grey relation method to analyze the structure of marine fishery human resources in China's coastal provinces and municipalities and the input control system in China's marine fishery management. Based on this, they proposed that China's marine fishery management should appropriately increase the input control of some factors.

On influencing factors of fishery development, Zhao *et al.* (Yu and Yu, 2011) used grey relation and GM (1,1) prediction model to take the fishery economic development of Fujian Province as an example, and established a model for evaluating the influencing factors of fishery economic development. Liu Huiyuan (Huiyuan *et al.*, 2014) and Li Yuangang *et al.* (Yuangang and Zhong, 2016) used the grey relation method to analyze the various influencing factors on the fishery economic output value, and analyzed each variable. The results showed that there was a grey relation between the fishery economic output value and the influencing factors. Using the grey system theory and methods can ascertain the interdependence between them, which not only have a scientific theoretical basis, but also are practical and feasible in practical work.

In the marine fishery industry structure, Li (Ningning, 2008), for the first time, used grey dynamic relational analysis method to analyze the relationship between the important components of the fishery industry and the overall fishery. Xu *et al.* (Ting and Chunlan, 2014) and Zhou *et al.* (Rui *et al.*, 2015) used the method of shifting share analysis and grey relation method to analysis fishery industry in Shanghai and Yunnan. Some problems in the optimization of fishery industrial structure were pointed out and corresponding countermeasures were proposed.

From existing studies, it can be seen that using existing data to evaluate and predict marine fisheries based on the grey system theory is an important aspect of studying traditional marine industries, but how to quantitatively assess in external the suddenly changed data and embedding the grey prediction model make the grey prediction model satisfy sudden changes in the external conditions of the data. It is also a research topic that should be focused in the future.

4.1.2 The application of grey methods in emerging marine industries. Today, with the rapid development of the marine economy, it is importance to open up emerging marine industries to promote the development of the marine economy. The emerging industries in the ocean have different characteristics and growth patterns from traditional industries. Therefore, the development of new marine industries does not mean the same with the traditional marine industry. The government should have ideas, policies and institutional innovations in supporting the development of emerging industries regarding the ocean. The rapid development of emerging marine industries drives the steady development of the marine economy. On the research of emerging marine strategic industries, Yin *et al.* (Kedong *et al.,* 2009) first applied grey relational analysis to quantitative analysis of land–ocean economic effect in 2009 and proposed the construction of marine high-tech industrial clusters and the integration of land and sea economy. Mao *et al.* (Wei and Zhanjie, 2012), Deng and Teng *et al.* (2013) used grey relational analysis method to analyze the development of China's marine strategic emerging industries and the correlation of industrial structure and pointed out that emerging marine industries still needed to develop. Yu *et al.* (2013) and Bai *et al.* (Bai and Zhou, 2015) used the grey-weighted clustering method and the grey development decision model to propose a strategic choice in line with the blue economic zone and the development of the marine industry. Yin *et al.* (2016) studied the influencing factors of strategic marine emerging industries based on the GRARP grey relational model in 2016, and explained that education, investment and marine technology had a greater degree of relationship with strategic marine emerging industries. This is the latest research progress in the field of marine emerging industries.

In the field of offshore oil and gas industry, many scholars have also done a large number of studies using grey relation analysis and grey relation analysis methods. Fu *et al.* (2009) established an indicator system based on Guangdong's marine output value and used nine marine industries as reference series for grey relation analysis in 2009. He *et al.* (He and Song, 2013) used the grey relation analysis method and input–output method to analyze the relational and ripple effects of the ocean industry from the perspectives of the marine industry and the land–ocean industries. Wu *et al.* (Wu and Huang, 2013) and Zheng *et al.* (Zheng and Jiang, 2014) used the grey relation analysis method and multi-level grey assessment method to analyze the relationship between the related factor index and the marine equipment market performance, and performed the safety assessment of the oil pipeline system. The quantitative results of the reliability of the oil pipeline in service were provided and it illustrated the practicality of the grey theory approach.

Many scholars use grey relational analysis, grey prediction model, grey development decision model, grey fixed weight clustering method and multi-level grey assessment method to study emerging marine strategic industries. Not only do scholars analyze the correlation between emerging marine industries, but they also put forward corresponding suggestions on the problems existing in the emerging industries for the future. Many researchers have made great contributions to the development of emerging marine industries. However, the applied methods are focused mainly on grey relation and grey prediction, making the research results not comprehensive.

4.2 The use of grey models for regional marine economic development research

Although the growth trend of the level of marine economic development in China's coastal areas is obvious, due to the regional differences in the development of marine economy, the development of marine economy in different regions is different. Among them, the areas with low level of development decreased gradually, and the areas with medium- and high levels of development increased gradually. Shandong, Liaoning, and Tianjin in the Bohai Rim region, Jiangsu, Shanghai, and Zhejiang in the Yangtze River Delta, and Guangdong in the Pearl River Delta have higher level of development, and the momentum was relatively strong. On the whole, with the establishment of a joint development plan for land–ocean joint development, China has begun to implement a marine development strategy driven by the central area. Research on regional marine economy has also begun to increase gradually; however, because of the small sample size, grey theory plays an important role in this research. In the development of marine areas, Yu *et al.* (2013) used the grey system theory and the Shandong Peninsula blue economic zone as the research object to construct an ocean-based emerging industry evaluation system. Huang *et al.* (2010), Zhang *et al.* (Zhang and Zhang, 2010) and Wang (Wang, 2012) applied grey relational theory to analyze the correlation of the marine industrial structure and development in Jiangsu, Liaoning and Shanghai, respectively. Fang *et al.* (2013) combined grey relation analysis with hierarchical TOPSIS to construct a quantitative model for sustainable development of marine economy in Zhejiang Province and conducted empirical analysis. Bai (2009) established the Guangdong marine economic GM (1, N) prediction model using the grey system theory to study and predict the marine economy of Guangdong Province. Lu *et al.* (2016) used the grey relational degree analysis and the coupling degree analysis method to quantitatively reveal the degree of correlation between economic development and the marine environment, and predicted the changes in the coupling relationship between Tianjin's economy and the marine environment from 2014 to 2018. It can be seen that the grey system theory is of great significance to the study of the economics of the marine region.

4.3 The application of grey models in marine research education

Marine scientific research and education are an internal driving force for the development of the marine economy. Factors that influence the development of marine scientific research education include marine scientific research institutions, marine science and technology projects, and scientific research personnel. Presently, scholars have made some achievements in research on marine research education. In terms of the input and output of marine science and technology, Yin *et al.* (Yin and Zhang, 2009; Zhong and Zhao, 2008; Liu and Cui, 2015) used grey relation analysis to study the relationship between scientific and technological inputs and marine economic growth. Among them, Yin also established an evaluation index system and established an evaluation model for the development level of marine science and technology, which greatly promoted the application of grey relation analysis in marine science and technology. In terms of marine professionals, Zhao *et al.* (Zhao and Li, 2010) used the GM (1,1) model to make predictions on marine talents. The results showed that the introduction of the GM (1,1) model in the grey system into the prediction of marine talents had the characteristics of model testability, simple parameter estimation method, and high prediction accuracy. It is a practical talent prediction method.

4.4 Marine environmental protection and disaster prevention and mitigation based on grey models

China is one of the countries with the most serious marine disasters in the world. The economic losses caused by ocean disasters are second only to floods and sandstorms inland. It is generally believed that marine disasters are disasters occurring on the ocean or in the coastal areas because the intensity of a particular oceanic process exceeds a certain limit, or an abnormality occurs in the local marine natural environment. Marine disasters mainly include storm surge disasters, wave disasters, sea ice disasters, tsunami disasters, red tide disasters, rising sea levels and coastal erosion. Marine disasters have a wide range of types, frequent occurrences and serious damages, posing a great threat to the development of coastal economies and the safety of people's lives and property. Therefore, the detection and early warning of the marine environment and the prediction of post-quake loss before the disaster will greatly promote the healthy and effective development of marine economic management. Due to the frequent absence of data and limited data in marine disaster, many scholars have applied the grey theory to the study of marine environment and disaster management and achieved good results. Yang *et al.* (1994) established the Verhulst model in 1994 to predict the development trend of seawater intrusion and provide decision-making information for further control of seawater intrusion. This is the earliest paper that used the grey prediction method to study marine disasters. Since then, many scholars have applied grey system theory and models to the study of typhoons, storm surges, tropical cyclones and heavy rain.

In terms of typhoon prediction, Qiao (Qiao *et al.*, 2012) and Shen (Shen *et al.*, 1999) used the grey prediction model to predict the typhoon location plan and the typhoon in Shanghai and its neighboring regions. They obtained good prediction results, showing that the grey prediction is relatively accurate. Wu (2001) used grey cluster analysis to calculate the early prediction factors in the number of typhoon landings so that the grey clustering analysis had a prediction function and also showed good results.

In the study of storm surge disasters, Gao (Gao *et al.*, 2016), Yin (Yin *et al.*, 2017), and Wang (2002) used the grey-period epitaxy model, grey relational model, and grey catastrophe prediction to predict the damage caused by storm surges and obtained good prediction results. However, it is difficult to predict natural disasters due to the great accidental nature of natural disasters. The grey theory is also very random in the prediction of storm surge disasters. The future is more applicable to many combinations of models to make predictions.

In the study of tropical cyclones, Zhou (2005) used the GM (1,1) model to predict the tropical cyclones on the southeastern coast of China, and simulated and tested the number of tropical cyclones that landed on the southeastern coast of China over a number of years. The report has been proved to have good results which also show the accuracy of the grey prediction model; Wu (Wu *et al.*, 2009), Xu (Xu and Liu, 2012), Liu (Liu and Chen, 2015) and Li (Li *et al.*, 2017) analyzed and evaluated the tropical cyclones and typhoons using grey relation analysis. The use of correlation analysis method to assess the level of tropical cyclone hazards is simple, easy in calculation and reasonable in assessment results; therefore, it can be used as a practical method for the classification of tropical cyclone hazards. However, due to the different types of disaster-based data used in the assessment and the single-index classification have different standards, the size of the correlation will change which will affect the division of the final disaster level.

In the study of floods and torrential rains, Lin (Lin *et al.*, 2017) used the grey relation method to analyze the correlation between flood peaks, typhoon storm floods, and non-typhoon storm flood peak flow and various factors. Additionally, he paves the way for the use of BP neural network methods. Cossarini (Cossarini *et al.*, 2014) applied the grey relation degree dynamic multi-attribute decision-making model to estimate the disasters of rainstorms and floods across the Chinese mainland from 2004 to 2009. The combination of grey relational analysis and dynamic multi-attributes decision making not only makes up for the unilateral deficiencies of the grey relational model, but also makes the predicted results more accurate.

Presently, there are few studies on marine disasters using grey system methods. On the one hand, there are also some problems in the application of grey systems to the prediction of marine disasters due to the lack of application of grey methods, such as the selection of series lengths. Grey prediction does not require long time series. The data time used should be an appropriate length of time series. If the series is too short, the information will be too little to participate in the calculation so that it is difficult to have enough information feedback. If the series is too long, it is difficult to achieve the smoothness required by the grey system also cause the failure of prediction. Additionally, the Marine Disaster Bulletin issues the bulletins a little later, only two years of predictions can be made on marine disasters. However, the two-year prediction has increased the possibility of errors to a certain extent. Therefore, how to improve the accuracy of long-span predictions is an issue that needs to be solved.

5. Conclusion

The grey system theory in marine economy and management provides scientific new methods and ideas for analysis, prediction, planning and decision making. The calculation is simple, required sample is small, and the result is objective and reasonable. The application of marine economy and management is consistent with the grey character of system analysis, which has high accuracy and efficiency of prediction, decision making, good practical application value and effect. As a subject under constant development and improvement, grey system theory has been preliminarily applied in marine economy and management, but it still needs further study. For the adoption of GM (1,1) model, the optimization of presto values needs to be considered further. Grey prediction includes series grey prediction, disaster forecast, seasonal reckoning grey prediction, topology of grey prediction and grey system prediction, etc., the first two of which has received certain attention, but the following three have not been applied into the marine economy and management fields. Grey control theory has not been applied into Marine economy and management.

As far as grey theory is concerned, its research depth is insufficient and its mathematical reasoning is limited. For example, grey relational analysis is not suitable for the analysis and calculation of negatively correlated series. Grey modeling and method of accumulative generation cannot abate the randomicity of the original series. The prediction model by the first-order differential equations inevitably has some problems such as the original errors, basic problems of grey theory that directly or indirectly influence the final modeling results. In particular, some core contents of grey theory, such as the conclusion that the accumulation of number series can improve the prediction accuracy, have not been strictly proved by mathematics in the existing grey theory, whereas as the core contents of grey theory, these conclusions are widely applied into various aspects of marine economy and management, and have a great influence on the final prediction results and accuracy. Therefore, the basis of grey theory research needs to be further strengthened, especially considering marine economy and management characteristics and should be given special attention to the improvement of grey theory method and the similarity of application conditions.

From the current research results, grey theory application in marine economy and management mainly concentrated in the major industries of the oceans, marine disasters, marine scientific research and education, marine environment, and marine disasters. Ultimately, the grey theory is mainly used in terms of interpretation and whose application field is too single. Presently, grey theory application in marine fishery and marine industry is mostly still limited to single series prediction, which also has certain errors. The ability of grey theory to solve various problems in marine economy and management is limited because of its flaws at the theoretical basis. In recent years, although there have been some examples of combinations of grey theory with fractal, neural network, fuzzy theory and other methods, the application scope and depth are far from meeting the practical needs. It can be combined with other optimization and simulation methods, such as genetic algorithm, mixed discrete variable multi-objective optimization algorithm, wavelet transform and least square method. Predictably, grey system theory on marine economy and management has a wide application prospect, which will be applied into the marine economy and management analysis, prediction, planning, design, decision making, etc. The combination of grey theory and other theory expands the idea of solving practical problems and overcomes the shortcoming of using grey theory alone, which must be researched further.

Acknowledgments

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