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Uncertainty and grey data analytics

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Abstract

Purpose – The purpose of this paper is to propose a framework for data analytics where everything is grey in nature and the associated uncertainty is considered as an essential part in data collection, profiling, imputation, analysis and decision making.

Design/methodology/approach – A comparative study is conducted between the available uncertainty models and the feasibility of grey systems is highlighted. Furthermore, a general framework for the integration of grey systems and grey sets into data analytics is proposed.

Findings – Grey systems and grey sets are useful not only for small data, but also big data as well. It is complementary to other models and can play a significant role in data analytics.

Research limitations/implications – The proposed framework brings a radical change in data analytics. It may bring a fundamental change in our way to deal with uncertainties.

Practical implications – The proposed model has the potential to avoid the mistake from a misleading data imputation.

Social implications – The proposed model takes the philosophy of grey systems in recognising the limitation of our knowledge which has significant implications in our way to deal with our social life and relations.

Originality/value – This is the first time that the whole data analytics is considered from the point of view of grey systems.

Keywords Uncertainty, Data incompleteness, Grey data analysis, Grey data analytics, Grey data collection

Paper type Research paper

1. Introduction

With the rapid development of big data technology and artificial intelligence (AI), we are increasingly living in a data-driven world where machine intelligence is assisting us in many parts of our life, such as journey planning, automatic driving, security control and health care service. As a result, our society is increasingly depending on the data we collected, and the quality of the data is determining the quality of our life. Although veracity has been recognised as another feature of big data in addition to its volume, velocity and variety (Wang and He, 2016), the significance of uncertainties has not received sufficient attention in the current big data oriented data analytics research and applications.

Big data sets usually assemble data from different sources with different accuracies and reliability, and the associated uncertainties can be even worse. The increased volume helps to deal with uncertainties like noise in defining probability distribution in many cases, but it does nothing with uncertainties like incompleteness and inconsistency. The variety and its associated diversity of data sources and interpretations can easily lead to wider fluctuations.

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and more significant uncertainties. As a result, the increased data volume might introduce even more uncertainties. Hariri et al. (2019) have pointed out in their recent paper that “little work has been done in the field of uncertainty when applied to big data analytics as well as in the artificial intelligence techniques applied to the datasets”.

Although the current research applications are heavily focussing on big data, small data does not disappear at all, and it is still a major challenge in many real-world data analytics. In some areas, data collection is expensive, and it is not realistic to carry out large number of costly experiments to collect data, such as the geological sampling in oil industry. In some cases, the nature of the data itself limits its possible amount, such as yearly GDP for a country, which is itself limited and small. Even if big data do exist, due to the completely change of environment and other determinants, only a small portion of data is still relevant, such as the social economic situation in China and the USA after the trade war. For small data, the impact of uncertainties is even bigger. To this end, the research in dealing with uncertainties in small data is more common than the case in big data. In addition to the mainstream methodologies based on probability distribution (Mostofian and Zuckerman, 2019), the theory of grey systems has achieved significant progress in dealing with small and incomplete data (Liu et al., 2016). Although the uncertainty representation and quantification in grey systems are developed for small data originally, its concepts and methodologies are applicable to big data as well (Yang and Liu, 2018). Hariri et al. (2019) listed most available uncertainty models with potential for big data, but grey model is missing in their list. Here, based on a comparative analysis of the existing uncertainty models, we discuss the feasibility of grey models for uncertainties in big data and the complementary feature between big data and small data models in data analysis, and propose the concept of grey data analytics (GDA).

Section 2 gives a review on the major uncertainty models available in computational intelligence, especially the related concepts in grey systems. Section 3 compares the available models in Section 2 and discusses the feasibility of grey models in uncertainty representation of big data. Then, Section 4 defines the concept of GDA and outlines its uncertainty representation framework. Following the proposed GDA, Section 5 discusses the complementary feature between big data and small data in GDA is also discussed. In the end, Section 5 concludes the paper.

2. Review of related uncertainty models
According to Cambridge Dictionary (Cambridge University Express, 2019), uncertainty refers to “a situation in which something is not known, or something that is not known or certain”. Considering the source of uncertainties, it can be classified as two different groups: subjective and objective. The subjective uncertainties are usually caused by our interpretation, such as our language descriptions. In this case, the object itself is certain, and the uncertainty is only caused by our subjective description. For example, the temperature for a specific time at a specific location is certain, but our feeling of “hot” or “cold” is a subjective description, which may change from one person to another. The objective uncertainty, on the other hand, is caused by the object itself rather than our description. For example, the weather tomorrow is unknown yet, and this “unknown” is not caused by our description, so it is an objective uncertainty. The two different types can certainly be combined together to form a more complicated situation where both subjective and objective uncertainties are at present. For example, “if tomorrow’s weather is hot” involves both subjective and objective uncertainties together. To deal with different types of uncertainties, a number of different models have been developed, such as probability (Feller, 1968), Bayesian (Bernardo and Smith, 2009) and belief function models (Guzzolin, 2014) for randomness, fuzzy sets (Zadeh, 1965) for fuzziness, rough sets (Pawlak, 1982) for roughness and grey systems (Deng, 1982) for greyness.
Among these models, probability models are the mainstream tools applied in both big data and small data analysis to deal with objective uncertainty. They are very effective for objective uncertainties caused by noise, such as randomness. Due to the convenience of the data-driven derivation of probability distribution, they are applied widely in many other related uncertainty models as well, such as Bayesian and belief function models. For uncertainties related with randomness, these models have been proved to be effective both for small data and big data. However, the overall probability can easily hide some specific local issues which may lead to ignorance of the locality of some uncertainty changes in the case of big data. Furthermore, probability models require probability distribution and assume randomness in uncertainties; this is not always applicable for uncertainty modelling when uncertainties other than randomness are involved. In addition to probability-related models, rough sets and grey systems are two models for objective uncertainties different from randomness, and fuzzy sets are defined for subjective uncertainty. The probability-based models are well known, and here we review only the basic concepts in fuzzy sets, rough sets and grey systems.

In human language, we have many terms to describe something between two extremes. For example, “very hot” is not the hottest, but it is more hot than most other candidates. If we consider the hottest and coldest as the two extremes, then “very hot” located between the middle point (neither hot nor cold) and the hottest. Obviously, we have a situation where something cannot be simply classified into one extreme entirely. To represent such a situation, Zadeh (1965) proposed the concept of fuzzy sets:

**Definition 1.** Fuzzy sets (Zadeh, 1965): let $U$ denote a universe of discourse. Then, a fuzzy set $A$ in $U$ is defined as a set of ordered pairs:

$$A = \{ (x, \mu_A(x)) : x \in U \},$$

where $\mu_A: U \rightarrow [0, 1]$ is the membership function of $A$ and $\mu_A(x)$ is the grade of belongingness of $x$ with regard to the fuzzy set $A$.

For each element $x$ in a set $A$, there is always a membership $\mu_A(x)$ to reveal the degree for the element $x$ belonging to $A$. This membership takes a value between 0 and 1, and it can be any value between the two extremes. In this way, the relationship between an element and a set does not necessarily be categorically belonging (1) or not belonging (0), and it could be partly belonging ($x < 1$) and partly not belonging ($x > 0$) at the same time. Such a facility frees the set definitions from the categorically extremes before, and makes it possible to represent concepts like “very much” and “slightly”. This is a revolutionary change for set theory. It should be noted that the object $x$ itself is determined, and the only uncertainty here is the fuzziness represented by the partial membership. It is our artificial ambiguous classification of $x$ to $A$ which causes this fuzziness, and it is completely a subjective justification. For example, if two different persons are asked to give their membership value for a government’s performance, more likely they come up with two different membership values for the same government under the same context. It shows that fuzzy sets are an ideal tool to describe subjective uncertainty.

There are many other extensions of fuzzy sets. The fuzzy membership values can be replaced with an interval, then an interval-valued fuzzy set (Sambuc, 1975) is obtained. It can also be replaced with two membership functions values, one for the membership of belonging to the set, and the other one for the membership not belonging to the set, which produces an intuitionistics fuzzy set (Atanassov, 1999). If the fuzzy membership itself is considered as a fuzzy set, it turns into a type-2 fuzzy set (Mendel and John, 2002). If the fuzzy membership is considered as a rough set, then it becomes an R-Fuzzy set (Yang and Hinde, 2010). If the interval membership is extended to include discrete set, it appears as a hesitant fuzzy set (Xu, 2014); if the membership values near to the two extremes and the rest are classified into three different groups, it leads to a shadowed set (Pedrycz, 1998), etc.
Rough sets provide a different facility to describe a set. It describes an undetermined set using approximations. There are many different interpretations of rough sets, here is a definition based on the set-oriented interpretation of rough sets (Yao, 1996):

**Definition 2.** Rough sets (Yao, 1996): let the pair $\text{apr} = (U, B)$ be an approximation space on $U$ and let the $U/B$ denote the set of all equivalence classes of $B$. $B$ is an equivalence relation on $U$. A set which is a union of the empty set $\emptyset$ and the objects of $U/B$ is called a definable set. The family of all definable sets in approximation space $\text{apr}$ are denoted by $\text{Def (apr)}$. Given by two subsets $A, \bar{A} \in \text{Def (apr)}$ with $A \subseteq \bar{A}$, the pair $(A, \bar{A})$ is called a rough set.

Different from fuzzy sets, a rough set approximates a set $A$ using two definable sets $A$ and $\bar{A}$. $A$ is known to be included by $\bar{A}$, and it contains $A$. The boundary region between $A$ and $\bar{A}$ represents the uncertain region where it is not known if it is part of $A$ or not. Therefore, the roughness can be measured using the cardinality of the uncertain region against the cardinality of the whole possible set $\bar{A}$.

**Definition 3.** Roughness of approximation (Sambuc, 1975): the roughness $R(A)$ for a set $A$ approximated by $(A, \bar{A})$ is defined as the significance of the uncertain objects to the set:

$$R(A) = \frac{|\bar{A} - A|}{|A|}. \quad (2)$$

The larger the boundary region is, the bigger the roughness is. The roughness will be 0 if the boundary region disappears when the two definable sets are identical. Considering the fact that a rough set is defined through partitions of the concerned domain (universe), a finer partition means a smaller boundary region and hence a lower roughness. In this sense, a rough set is defined through information granularity, and a finer granularity brings a more accurate approximation.

Fuzzy sets describe a set by means of fuzzy membership for the relationship between each element and the set. It indicates the strength of the belongings of an element to the set. For a rough set, however, it defines a set through approximation with two definable sets. Fuzzy sets focus on the subjective fuzziness, but rough sets highlight the objective roughness, and they are two different models for different uncertainties.

As a model for small and incomplete data, the theory of grey systems was first proposed by Professor Deng (1982). It divides systems into three different categories: white where everything is known, black where nothing is known and grey systems where part is known and another part is unknown. More specifically, grey systems take grey numbers and its associated degree of greyness as its fundamental concepts:

**Definition 4.** Grey numbers (Yang and John, 2012): let $\Omega \subset \mathbb{R}$ be the universe, $g^{\pm} \in \Omega$ be an unknown real number within a union set of closed or open intervals:

$$g^{\pm} \in \bigcup_{i=1}^{n} [a^{-i}, a^{+i}] \subseteq \Omega, \quad (3)$$

$i = 1, 2, ..., n$, $n$ is an integer and $0 < n < \infty$, $a^{-i}, a^{+i} \in \Omega$ and $a^{-i+1} < a^{-i} \leq a^{+i} < a^{+i+1}$. For any interval $[a^{-i}, a^{+i}] \subseteq \bigcup_{i=1}^{n} [a^{-i}, a^{+i}] \subseteq \Omega$, $p_i$ is the probability for $g^{\pm} \in [a^{-i}, a^{+i}]$.

**Definition 5.** Degree of greyness of a grey number (Yang and John, 2012): let $\Omega \subset \mathbb{R}$ be the universe and $g^{\pm} \in \bigcup_{i=1}^{n} [a^{-i}, a^{+i}] \subseteq \Omega$, $\mu$ is a measurement defined on $\Omega$. The degree of greyness of $g^{\pm}$ is defined as follows:

$$g^{\prime}(g^{\pm}) = \frac{\mu(g^{\pm})}{\mu(\Omega)}. \quad (4)$$
A grey number can be represented using an interval, a discrete set or a combination of both. Its associated uncertainty can be measured by its degree of greyness. In this way, a number with a known scope but unknown location can be represented by a grey number, and its associated degree of greyness.

In grey systems, a set with everything is known is called a white set, and a set with nothing known is called a black set. A set with only partial information known is referred as a grey set:

**Definition 6.** Grey sets (Yang and John, 2012): for a set \( A \subseteq U \), if the characteristic function value of \( x \) with respect to \( A \) can be expressed with a grey number \( g_A^+(x) \in \bigcup_{i=1}^{n} [a_i^-, a_i^+] \in D[0, 1]^\pm \):

\[
\chi_A : U \rightarrow D[0, 1]^\pm. \tag{5}
\]

then \( A \) is a grey set.

The characteristic function takes value as a grey number between 0 and 1. It could be represented with an interval, a discrete set or a combination of intervals and discrete values. When the two extremes of the grey numbers meet together, it becomes a single number. If the characteristic function is a fuzzy membership function, a fuzzy set defined in Definition 1 is obtained. Therefore, a fuzzy set is a special case of a grey set. Each element in a grey set is associated with a grey number, so a degree of greyness can be defined for each element:

**Definition 7.** Degree of greyness for an element (Yang and John, 2012): let \( U \) be the finite universe of discourse, \( x \in U \). For a grey set \( A \subseteq U \) the characteristic function value of \( x \) with respect to \( A \) is \( g_A^+(x) \in D[0, 1]^\pm \). The degree of greyness \( g_A(x) \) of element \( x \) for set \( A \) is expressed as follows:

\[
g_A(x) = |g^+ - g^-|. \tag{6}
\]

With the degree of greyness of each element, the degree of greyness of a set is a natural description of the uncertainty of a grey set:

**Definition 8.** Degree of greyness for a set (Yang and John, 2012): let \( U \) be the finite universe of discourse, and let \( A \subseteq U \) be a grey set. Assume \( x_i \) is an element relevant to \( A \) and \( x_i \in U \). Let \( i = 1, 2, 3, \ldots, n \) and \( n \) is the cardinality of \( U \). The degree of greyness of set \( A \) is defined as follows:

\[
g_A = \frac{\sum_{i=1}^{n} g_A(x_i)}{n}. \tag{7}
\]

The degree of greyness is a convenient indicator for information incompleteness, but it still needs other measurements to different some special situations, such as the relative uncertainty (Yang et al., 2014).

### 3. Comparative analysis of the existing models and their feasibility for data analytics

In our previous work, it has been proved that these existing uncertainty models are closely related with each other although they have difference as well (Yang and John, 2012). In Definition 6, the characteristic function is equivalent to a fuzzy membership function when its resulted grey number becomes a white number (the two extremes meet together). In this special case, it turns out to be equivalent to a fuzzy set. In this sense, a white set without greyness can still be fuzzy. It shows that the greyness is different from fuzziness, and they represent different uncertainties. Greyness is caused by incomplete information of the
object, and it is objective. A grey set can be turned into a white set when more information is added. However, this is not the case with fuzzy sets, no matter how much information is added, a fuzzy set is still fuzzy. Fuzziness is caused by our ambiguous classification of objects; this subjective uncertainty has nothing to do with incomplete information. Therefore, a grey set combines objective uncertainty together with subjective uncertainty. In fact, those extended fuzzy sets have also combined objective uncertainties with subjective uncertainty in some way. A fuzzy membership value itself is subjective, but its incompleteness is actually objective. Therefore, those extended fuzzy sets overlap with grey sets in many cases. For example, both interval-valued fuzzy sets and hesitant fuzzy sets overlap with grey sets significantly under some conditions. However, there is a crucial difference between them: a grey set is a single valued set even if its characteristic function is represented as a grey number, but interval-valued fuzzy sets or hesitant fuzzy sets are still multi-valued sets.

Similar to grey sets, rough sets focus mainly on objective incomplete information as well. It is the incomplete information which led to coarse partitions over a given information system. Different from grey sets and fuzzy sets that take individual characteristics function values of each element to define the set, a rough set is approximated through two definable sets constructed from the available information. If more information added, the partition can be finer which leads to a better approximation. In this way, the set could be accurately defined when the two definable sets become identical. Therefore, similar to grey sets, a rough set can be turned into a definable set when all information required is available. Although both grey sets and rough sets are dealing with objective uncertainty, they are quite different from probability models which are still uncertain even if more information is available. Randomness is actually independent from incompleteness. However, data incompleteness due to small data size may have impact on the measurement of probability. In this sense, an increased data size may lead to a more accurate probability, but it will not remove randomness from the data.

Let $U$ be the universe, and $A$ is a set defined on $U$. For any element $x$ in $U$, $\mu_{A}(x)$ is the fuzzy membership value for $x$ belonging to $A$; $g_{A}(x)$ is the degree of greyness of $x$ in $A$, and $g_{A}$ is the degree of greyness of $A$; $(\underline{A}, \overline{A})$ is the rough approximation of $A$; $p_{A}(x)$ is the probability distribution of $x$. $i$ is the available information or data. Then, we have the following properties:

- $\lim_{i \to \infty} \mu_{A}(x) = \mu_{A}(x)$;
- $\lim_{i \to \infty} g_{A}(x) = 0$ and $\lim_{i \to \infty} g_{A} = 0$;
- $\lim_{i \to \infty} |\overline{A} - \underline{A}| = 0$; and
- $\lim_{i \to \infty} p_{A}(x) = p_{A}(x)$.

The first one and the last one show that the subjective fuzziness and the objective randomness do not change when more data are available. However, the increased data may turn a grey number or a grey set into a white number or a white set as shown in the second one. The third one indicates that a rough approximation can become accurate when more data are available. The 0 cardinality of their boundary set means that every element in the universe has a known relationship with the set $A$: either in or out.

The impact of available new data or information on different models is shown in Figure 1. The addition of new data or information can remove the information incompleteness, so it leads to a white set from a grey set, or a definable set from a rough set. For probability models and fuzzy sets, the additional information does not change their randomness or fuzziness at all. In real-world applications, however, there are many situations where a probability or fuzzy
membership adopted to represent the incompleteness as well, and it is certainly true that such “fuzziness” and “randomness” would change when more data or information become available.

From this property, it is clear that both probability models and fuzzy sets target on uncertainties that do not change with the amount of data available. Compared with probability model and fuzzy sets, grey sets and rough sets focus on information incompleteness, and provide feasible models to consider incompleteness in data sets. In data analytics, randomness has been well defined by probability models and its derived models (Hariri et al., 2019). Fuzziness has also been implemented in fuzzy database (Petry and Bosc, 1996). However, there is no systematics way in dealing with information incompleteness so far. In relational databases, incomplete information is mainly represented by “null” marks (Date, 2000) in relational databases. It refers to either applicable but unknown, or not applicable. This is a very restrictive representation, and it cannot express partial information where some incomplete information might be available. For example, a person’s salary might be known between £30,000 and £40,000, but the exact number is not known. With the “null” mark, this available information is not possible to be represented, hence we lose available information. In big data, incomplete data are mainly treated by data imputation (Shobha and Nickolas, 2018) in data pre-processing. However, no matter what imputation methods taken, the derived values are not a factual value and it is not as reliable as other values. These can cause significant problems later on. For example, an image with pedestrian in the road might be a rare case; an imputation from other images might end up with suggestions for the car to cross over it. If the pre-processed data are prepared by imputation, the intelligent system established from such data has no way to detect this, and it might cause serious problem in the end. A much preferred way to deal with it is to preserve the original information as accurate and precise as it is, and catch up the existence of uncertainty in its application stage. In this way, the established intelligent system has a chance to take care when such uncertainty is involved. Following our aforementioned analysis, it is clear that grey sets and rough sets have potential to facilitate such a representation.

Similar to our previous discussion on the difference between grey sets and extended fuzzy sets, a grey set is a single valued set whereas a rough set is a multi-set. A grey set can be considered as a singleton rough set with an empty lower approximation. In terms of its partition, there is only one participation included in the rough set and it is known that there is only one element in the partition belonging to the set although other elements in the partition cannot be separated due to the limited known information. Therefore, rough sets could be applied if multi-set representation is necessary. Here, only singleton values are considered, so we focus mainly on the application of grey sets and grey systems in data analytics.

Although grey systems are mainly focussing on small and incomplete data sets, the definition of grey sets does not exclude data sets with large size. In fact, as aforementioned, a big data set consists of many small data sets, and the summarisation of a big data set still leads to small data sets. There are always occasions where small data sets are necessary even if in big data. In this sense, a combination of big data with small data through grey sets is an ideal option to deal with uncertainties in data sets, being it big or small.

![Diagram of Uncertainty and grey data analytics](image)

**Figure 1.** The impact of new information to uncertainty models
4. Grey data analytics (GDA)

With the development of Industry 4.0 (Popkova et al., 2019) and Society 5.0 (Salgues, 2018), our society is developing towards a direction where everything is connected to provide data to enable intelligent machines to help people in nearly every aspect of our life. The human society is speeding up into an unknown situation where machines and human are mixed together in a much more interactive way. The ability to deal with unknown situations is a nature of human which machines have failed to grasp so far. However, the competition of AI applications between countries means we have to deal with this challenge nowadays. Data analytics is the foundation of AI applications, and a machine can only be as clever as it can grasp from its data. One of the most common uncertainties in data analytics is data incompleteness, such as missing values, incomplete values and inaccurate values. Due to the imperfect devices for data collection, dynamic environment and human errors, the incompleteness is inevitable in a data set, and it is more serious for a large data set assembling data from different sources. The current data pre-processing like data imputation effectively hide these uncertainties from users, which helps the data processing later on but may bring in false inputs to data analysis and lead to serious problems. For example, a traffic accident is definitely rare in a traffic data set recording traffic situation for years. If some data for the accident are missing, a data imputation will more likely to derive data from normal data sets, which effectively remove accident from the database. We can imagine what will happen if a driverless car acts according to such kind of intelligence. Nearly all data analysis tools prefer exact values in data analysis, and assume that all data are perfect reflection of the real-world situations. Although this method is applicable in most cases without significant problems, it has a fundamental problem in that it cannot deal with unknown situations. To avoid such problems, it is essential to take data imperfection as a nature, and make it an essential part for every operation in data analytics.

Applying the concept of grey sets, we consider everything in data analytics as grey in nature. It includes data samples, data storage and data analysis tools. For example, a data sample may not be completely known and there might be some unknown components, a big data set can be considered as a grey set consisting of data samples as elements, as shown in Figure 2. Then their uncertainty measurement can be derived using Equation (7).

Figure 2.
Data samples and grey sets
Similarly, an analytical tool may also be partly known and partly unknown, and its results are also grey (partial known). In this way, the process of data analytics can be turned into a process taking all data and tools as grey in nature, and carrying out grey data management, grey analysis and grey decision making. Such a data analytics has a crucial difference from the current one: it highlights the uncertainty rather than hiding it, and we call it GDA, as shown in Figure 3.

In Figure 3, the grey data management refers to all facilities and operations to collect and manage data with uncertainties. It involves data collection, data pre-processing and imputation, data representation and storage and data management. The grey tools indicate various data analysis tools whose operations introduce further uncertainties, such as its accuracy, reliability, etc. There grey tools have to take account the data incompleteness and its own associated incompleteness. The grey decision support is the final stage of the grey data analysis. The results from the last stage need to be processed and interpreted with incompleteness involved so as to provide support to business decision making.

4.1 Grey data management
The grey data management refers to the first stage in GDA. It includes grey data collection, grey data imputation, grey data storage and management as shown in Figure 4.

For data collection, data requirement is the first step for the whole process. For a given business requirement at a specific environment and time, there are always incomplete information involved for the data requirement. For example, it is usually not clear in the beginning what kind of data analysis will be involved later on, and what are the influential factors in the data analysis. It leads to an incomplete data requirement which needs to be refined. However, it is difficult to know when we do not have a complete picture of data requirements, so it is usually the case that data collection starts with an incomplete data requirement. Having established the data requirements, then a strategy to collect data has to be designed, such as the devices to be used, location to be selected, time to collect the data, the people who collect the data, etc. Together with data collection strategy, a specific data representation has to be determined for the data to be collected, such as its format,
components, accuracy and errors representation, etc. Obviously, all these may introduce data incompleteness, such as neglected important components, wrong formats, unfitted accuracy or error representation. Furthermore, any environment change during the data collection, such as temperature, humidity, social events, etc., can introduce further errors and unexpected fluctuations. To make it even worse, different persons may have different skills and knowledge on data collection, which may introduce human errors and differences. All these can potentially introduce data incompleteness in data collection, as shown in Figure 5.

In GDA, the incompleteness will be captured right from the data collection stage. Each data sample will be represented as a grey data set, with grey number as its underlined representation of its incompleteness.

Having collected data, the next step is pre-processing, such as data cleaning and imputation to improve the data quality. The current data imputation simply removes uncertainty from data and makes it no difference from other fact data. In GDA, instead of convert unknown into an unreliable known value, the imputation will target to reduce the degree of greyness and other uncertainty measurement rather than completely remove uncertainty. If no other information available, a grey data or even black data will be kept instead of an imputed “white” data. The difference between the imputations of GDA and the current data analytics is shown in Figure 6.

For the data after grey imputation, a data representation and storage strategy has to be drawn to keep not only the data values itself but also all the information on its incompleteness/greyness. To this end, a single value represented by multi-valued sets has to
be facilitated in data storage facility. For relational databases, this requirement does not conflict with its requirement of a single value cell in tables; however, a storage of a set representing this single value has to be enabled. For unstructured databases, this is not an issue. With such a data storage, corresponding data retrieval and data manipulation will have to facilitate such data as well. In relational model, the involvement of grey data makes operations like left join, right join and full join more common than they are in the present relational queries. For unstructured data, similar mechanism for data with grey numbers will have to be facilitated as well.

4.2 Grey data analysis

There have been many data analysis tools available in the market, and most of these tools assume perfect data as inputs and give perfect data as outputs as well. However, it is not only the input data could be grey, the tools themselves could also add further uncertainties into the process. No matter what tools we are using, they involve many parameters for their computation. In most cases, these parameters are some kind of approximation and will introduce errors and bias. In addition to this, the way to use these tools can also lead to new incompleteness to the system, such as the specific structure and algorithm chosen when many different alternatives are available, as shown in Figure 7.

In GDA, all processes implemented by data analysis tools are considered as grey, and hence associated with degree of greyness as well. By combining the uncertainty from tools and the uncertainty from data, it is possible to derive its propagation from inputs to outputs with respect to the specific operations of each individual tool. Such an operation will certainly reveal more information for intelligent systems to take right actions with full consideration of various possibilities.

In addition to the benefit from uncertainty tracking, GDA provides another possibility to combine the data analysis tools for big data and small data together as well. Although big data has significantly enhanced the application of AI, there are still real-world situations where big data technology cannot work and models for small data are still essential (Kennedy et al., 2017; Martin-Diaz et al., 2017; Thinyane, 2017). It is well known that grey prediction models work better for small data sets while models like neural networks work better for big data sets. The two different tools are usually used in different situations separately. However, they do have different merits and are complementary to each other. The big data models have strength in evaluating the long-term and large-scale analysis and prediction, and it is reliable when a general consideration on large scale over long-term period. However, it is not good to evaluate a very specific location at a specific time due to the impact of data from other areas and time. On the contrary, the grey models are good at local and short duration predictions, but they struggle with large-scale analysis. Based on

![Figure 7. Uncertainty from data analysis tools](image)
the common facilities for grey data in GDA, the two different models could be combined together to cover both large-scale and small area, long duration and short-term analysis. The big data model will be called first to conduct general analysis and prediction for long term and large area. Then the identified interesting locations and time slots will be focussed and related data will be extracted from large data set into a small data set, and then a grey model will be called upon to carry out local and short-term prediction so as to give further result specific to an identified location and time period. In this way, we can make full use of their different merits, as shown in Figure 8.

4.3 Grey decision support

In data analytics, all the data management and data analysis facilitate the final step – decision-making support. For GDA, this step involves construction of candidate solutions from GDA, comparison, ranking and optimisation of these candidate solutions and then the final grey decision making, as shown in Figure 9. The results from grey data analysis are usually grey in nature, and a full consideration of these grey results will lead to more candidate solutions than the current data analytics. The task to compare, rank and optimise these solutions is even more challenging, and may involve an iteration back to grey data analysis as well. Various models can be involved, such as grey incidence analysis, grey clustering, fuzzy clustering, linear programming, evolutionary algorithms, etc. The result is then fed into grey decision making where a final recommendation can be drawn in terms of visualised or other user friendly forms.

Figure 8. The combination of big data models with small data models

Figure 9. Grey decision-making support
5. Conclusions
Based on a comparative analysis of the existing uncertainty models, the feasibility of grey sets and grey systems in representing information incompleteness is investigated. The analysis shows that grey sets and grey systems are an ideal option in capturing uncertainty like information incompleteness not only for small data but also big data. On the basis of this comparative analysis, GDA is proposed as a novel concept for data analytics. The data collection, imputation, storage and management are then discussed, and the data analysis for grey data with full consideration of the possible imperfection of analysis tools is then analysed. The additive advantage to combine the big data analysis with small data model in data analysis stage is then highlighted. Based on the grey data management and grey data analysis, the process of their results for grey decision making is then discussed. The analysis in this paper shows that the proposed GDA opens a brand new field to be explored for the incoming AI enabled society. It will enable a better human machine coexistence and improve people’s trust on AI. As the first step, this paper focusses mainly on the concept and there are much more work needed to get its full potential.

References
Date, C.J. (2000), An Introduction to Database Systems, Addison-Wesley, p. 938.
Further reading


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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

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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 Pae, 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 FGM (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
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>
<thead>
<tr>
<th>Language of articles</th>
<th>Grey relational analysis</th>
<th>GM (1,1) prediction model</th>
<th>Grey multivariate prediction model</th>
<th>Grey prediction record counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinese</td>
<td>8,181</td>
<td>2,835</td>
<td>309</td>
<td>3,144</td>
</tr>
<tr>
<td>English</td>
<td>2,042</td>
<td>985</td>
<td>80</td>
<td>1,065</td>
</tr>
<tr>
<td>Total</td>
<td>10,223</td>
<td>3,820</td>
<td>389</td>
<td>4,209</td>
</tr>
<tr>
<td>Proportion (%)</td>
<td>70.84</td>
<td>26.47</td>
<td>2.70</td>
<td>29.16</td>
</tr>
</tbody>
</table>
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.

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

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](image-url)

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
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>
<thead>
<tr>
<th>Rank</th>
<th>Countries and regions</th>
<th>Frequency</th>
<th>Centrality</th>
<th>Countries and regions</th>
<th>Frequency</th>
<th>Centrality</th>
</tr>
</thead>
<tbody>
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<td>China</td>
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</tr>
<tr>
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<td>Taiwan</td>
<td>224</td>
<td>0.07</td>
</tr>
<tr>
<td>3</td>
<td>India</td>
<td>357</td>
<td>0.39</td>
<td>USA</td>
<td>88</td>
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</tr>
<tr>
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<td>England</td>
<td>45</td>
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</tr>
<tr>
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<td>0.09</td>
<td>Turkey</td>
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<tr>
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<td>Canada</td>
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</tr>
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<td>7</td>
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<td>Australia</td>
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<td>0</td>
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<td>Iran</td>
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<td>Canada</td>
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<td>Japan</td>
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<td>0</td>
</tr>
<tr>
<td>10</td>
<td>England</td>
<td>18</td>
<td>0.04</td>
<td>South Korea</td>
<td>10</td>
<td>0.02</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Model</th>
<th>Rank</th>
<th>Institutions</th>
<th>Frequency</th>
<th>Centrality</th>
</tr>
</thead>
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<tr>
<td>analysis</td>
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<td>National Institute of Technology</td>
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</tr>
<tr>
<td></td>
<td>3</td>
<td>Nanjing University of Aeronautics and Astronautics</td>
<td>38</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>University of Chinese Academy of Sciences</td>
<td>38</td>
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<td>5</td>
<td>Luangwa University of Science and Technology</td>
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<tr>
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<td>Anna University</td>
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</tr>
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<td></td>
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<td>Northwestern Polytechnic University</td>
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</tr>
<tr>
<td></td>
<td>8</td>
<td>Shanghai Jiao Tong University</td>
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<td></td>
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<td>Yampi University</td>
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<tr>
<td></td>
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<td>Jilin University</td>
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</table>

<table>
<thead>
<tr>
<th>Grey prediction model</th>
<th>Rank</th>
<th>Institutions</th>
<th>Frequency</th>
<th>Centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td></td>
<td>2</td>
<td>North China Electric Power University</td>
<td>27</td>
<td>0.03</td>
</tr>
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<td></td>
<td>3</td>
<td>National Cheng Kung University</td>
<td>22</td>
<td>0.01</td>
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<tr>
<td></td>
<td>4</td>
<td>Lanzhou University</td>
<td>21</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Wuhan University of Technology</td>
<td>19</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
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<td>Zhejiang University of Finance and Economics</td>
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<td>0.01</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Chongqing Technology and Business University</td>
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<td>8</td>
<td>De Montfort University</td>
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<tr>
<td></td>
<td>10</td>
<td>Dongbei University of Finance and Economics</td>
<td>13</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Figure 8.
The keywords map of grey relational literature

Figure 9.
The keywords map of grey prediction 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.

<table>
<thead>
<tr>
<th>Rank</th>
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<th>Grey prediction model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Keywords</td>
<td>Frequency</td>
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<td>Optimization</td>
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<td>Taguchi method</td>
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<td>Parameter</td>
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<td>System</td>
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<tr>
<td>7</td>
<td>Neural network</td>
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</tr>
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<td>8</td>
<td>Design</td>
<td>130</td>
</tr>
<tr>
<td>9</td>
<td>Performance</td>
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<tr>
<td>10</td>
<td>Surface roughness</td>
<td>112</td>
</tr>
</tbody>
</table>

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
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

<table>
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<tr>
<th>Model</th>
<th>Rank</th>
<th>Category</th>
<th>Frequency</th>
<th>Centrality</th>
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<td>Operations research and management science</td>
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<td>Science and technology – other topics</td>
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</tr>
<tr>
<td></td>
<td>6</td>
<td>Operations research and management science</td>
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<td>Business and economics</td>
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<td>Water resources</td>
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<td>Automation and control systems</td>
<td>45</td>
<td>0.02</td>
</tr>
</tbody>
</table>

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 Yang-geet, 2005; Kedong et al., 2007; Ke-dong and Zi-qiang, 2008) 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 Huiyu (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 analyze 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 Zhanje, 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...
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
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 prevo 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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**References**


Deng, J.L. (1990), Grey System Theory Course, Huazhong University of Science and Technology Press.


Song, Z.G. and Deng, J.L. (2001), “Reverse accumulation generation and grey GOM (1,1) model [D]”.


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Environmental pollution and economic growth elasticities of maritime and air transportations in Iran

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Abstract
Purpose – The purpose of this paper is to examine the effects of maritime and air transportation on the environment and economy of Iran. The authors specify two dynamic models of the environmental pollution and the economic growth. Then, the authors estimate the environmental and economic elasticities of maritime and air transportation in short run and long run in Iran during 1978–2012.
Design/methodology/approach – The authors estimate the environmental and economic elasticities of maritime elasticities in short and long run, using simultaneous equations system.
Findings – The findings indicate that the short- and long-run environmental pollution elasticities of maritime transportation are higher than those of the air ones. In addition, the economic growth elasticities are greater in the air transportation compared to maritime one. As a result, the maritime transportation is more pollutant and less productive in Iran in comparison with the air transportation.
Originality/value – The policymakers are advised to improve the infrastructure of maritime transportation from both the environmental and economic point of views. Consequently, the air transportation is considered as a cleaner and more beneficial transportation mode in Iran, where geographical position limits the maritime transport as a widespread transportation mode.
Keywords Iran, Economic growth
Paper type Research paper

1. Introduction
Transportation plays an important role in the environmental pollution and economic growth. According to IEA (2009), about 25 percent of the world’s energy is attributed to transport and about 5 percent of this energy is responsible for the whole environmental changes, while projecting that this amount will be likely to increase 50 percent by 2030 and 80 percent by 2050. As shown in Figure 1, transportation boosts the international trade and...
technical efficiency, and stimulates the economic growth. Economic growth, in turn, causes the environmental pollution. In addition, transportation has conflicting effects on the environmental pollution. It consumes a high volume of fuels and pollutes the environment; whereas it can reduce the environmental pollution with higher efficiency in carrying the cargos, like maritime transportation (Farhani et al., 2014; Taghvae et al., 2017).

There are four modes of transportation including road, rail, air and maritime transportation. Among them, maritime transportation has the highest potential for carrying goods in high volume; and air transportation is the fastest mode of transportation, boosting the economic growth. Nonetheless, both pollute the environment due to consumption of high volumes of fossil fuels (IEA, 2009; Taghvae and Hajiani, 2015; IMO, 2016; Larkin et al., 2016; IATA, 2014). Globally, transport energy use increased steadily at between 2 and 2.5 percent per year during 1971–2006. Figure 2 shows transport energy use by mode in the world in 2008. Maritime and air transportation show the highest shares, after road transportation which ranks the first (IEA, 2009).

Maritime transportation is of the largest capacity for shipping commodities; and the air one is the most rapid mode. Both maritime and air transportation modes increase the flows of the international trade, and encourage the economic growth (Taghvae and Hajiani, 2015; IMO, 2016; Larkin et al., 2016; IATA, 2014).

As mentioned earlier, these modes of transportation increase the environmental pollution. Figure 2 shows the extrapolation of CO₂ emissions among the modes of transport
Maritime transportation plays a dual role in the CO₂ emissions, especially in the countries, which have access to the open seas like Iran. As Figure 4 shows, Iran is among the most pollutant countries in terms of CO₂ emissions from maritime transportation. On the one hand, it can increase carbon dioxide emissions due to the high volume of cargos, since cargo shipping requires burning an extremely high volume of fuels, which emits considerable CO₂ (Taghvaee and Hajiani, 2015). On the other hand, it can mitigate environmental pollution because of economies of scale in carrying bulk cargos (IMO, 2016).

Thus, transportation by ships and aircrafts has various effects on the economic growth and environmental pollution, specifically in the geo-strategic countries such as Iran, which connects the East to the West. In this regard, the environmental and economic effects of air and sea transportation are comparable with each other (Larkin et al., 2016; IATA, 2014).

Figure 3.
CO₂ emissions from various modes of transportation in the world


Figure 4.
Global CO₂ emissions

Data Source: exactEarth, IHS and ArcGIS
© International Council on Clean Transportation, 2017

The purpose of this study is to compare the maritime transportation effects with air transportation ones on the environment and economy of Iran in order to seek the most efficient and the cleanest transportation mode.

2. Methodology and model

We compare the environmental and economic effects of maritime and air transportation in the short and long run in Iran during 1978–2012 using two dynamic log-linear models. Following Farhani et al. (2014), Taghvaei et al. (2017) and Taghvaei and Hajiani, we specify the models as follows (IMO, 2016; Larkin et al., 2016; IATA, 2014):

\[ LCO_{2t} = x_0 + x_1LM_t + x_2LA_t + x_3LY_t + x_4LCO_{2t-1} + x_5D_t + \epsilon_t, \]

\[ LY_t = \beta_0 + \beta_1LM_t + \beta_2LA_t + \beta_3TR_t + \beta_4LY_{t-1} + \beta_5D_t + \mu_t, \]

where \( CO_2 \) is carbon dioxide emissions, \( M \) and \( A \) denote maritime and air transportation modes, respectively. \( Y \) is GDP, and \( TR \) is trade volume. \( \alpha \)s and \( \beta \)s show the parameters of models. \( D \) is the dummy variable which is set 0 for the war years (1980–1989) and 1 for the remaining years. \( L \) is the natural logarithm; \( t \) is year; \( \epsilon \) and \( \mu \) are the error terms. \( \alpha_1, \alpha_2 \) and \( \alpha_3 \) are the short-run elasticities of environmental pollution and \( \beta_1, \beta_2 \) and \( \beta_3 \) give the short-run elasticities of the economic growth. The long-run elasticities are \( \alpha_1/1-\alpha_4, \alpha_2/1-\alpha_4, \alpha_3/1-\alpha_4 \) for the environmental pollution; and \( \beta_1/1-\beta_4, \beta_2/1-\beta_4, \beta_3/1-\beta_4 \) for the economic growth (Sene, 2012). Before running the models, we check the variables for the unit root, preventing the spurious regression. The regressions with non-stationary variables are not reliable statistically. This study applies the Augmented Dickey–Fuller (ADF) unit root test as the most common test for stationarity (Taghavee and Hajiani, 2014; Taghvaei et al., 2017).

3. Data

The annual data are derived from World Development Indicator (2014), except for the maritime and air transportation variables, which come from the Central Bank of Iran (Economic Research and Policy Department of Iran, 2016). The per capita sea and air transportation of goods are measured in metric ton per person. The per capita \( CO_2 \) emission, measured in metric ton per person, is the proxy for the environmental pollution. The per capita GDP, measured in constant 2005 US\$ per person, is the proxy for the economic growth. Trade, measured as the percentage of GDP, is the proxy for trade openness.

All data are in natural logarithm, which are represented in the appendix of the paper after the references. Figures 5 and 6, respectively, display the logarithms of per capita maritime and air transportation volume. With regard to Figure 5, maritime transportation has grown substantially over the period 1978–2012, raising a question: whether its growth is consistent with environmental and economic infrastructure (Parsa et al., 2019). Figure 6, however, displays that the air transportation has not experienced higher growth rates. This might be caused by misallocation of budget for this transportation mode. Figure 6 is another evidence for the low investment in air transportation in comparison with the maritime transportation.

Figure 7 represents the number of ships and planes in proportion to the number of ports and airports in Iran in 2015. It shows a high intensity of maritime transportation in comparison with the air mode, supporting the lower investment in the latter mode.

Figures 8 and 9 exhibit the per capita \( CO_2 \) emissions and GDP in natural logarithms. Based on Figure 8, per capita \( CO_2 \) emission has increased moderately in the period under study, which is an evidence against the sustainable development in Iran. In other words, the development process of Iran is inconsistent with the environmental considerations, urging regulations that are more stringent, specifically in the transportation infrastructure. Figure 9, however, does not show a considerable increase in economic growth in Iran in the
Figure 5.
Logarithm of per capita maritime transportation volume
Source: Central Bank of Iran, 2018 (Economic Research and Policy Department of Iran, 2016)

Figure 6.
Logarithm of per capita air transportation volume in Iran
Source: Central Bank of Iran, 2018 (Economic Research and Policy Department of Iran, 2016)

Figure 7.
The ratio of ship/airplane fleet to air/ports in Iran (2015)
same period. It suggests that the development process does not match economic growth. Transportation infrastructure, for example, should be reformed to support economic growth efficiently in Iran. In general, the development process in Iran lacks considerable growth and environmental sustainability.

For a more accurate analysis, we run Models (1) and (2) to estimate the environmental pollution and economic growth elasticities of maritime and air transportation.

4. Results
As earlier said, testing against unit root is the first stage of estimation of a time series model. Table I reports the results of ADF unit root test. In this test, the null hypothesis implies unit root and non-stationarity of a series.

Based on the results, all variables are stationary in level. Accordingly, it confirms that the regressions are not spurious and thus, we run the models without concerning about the spurious regression results.

Table II represents the estimation results of the environmental pollution model. All coefficients are statistically significant at the 5 percent level of significance. These coefficients show that the environmental pollution is inelastic with respect to maritime and air transportation.
air transportation modes and per capita GDP, both in the short and long run. The short-run elasticities of environmental pollution with respect to maritime and air transportation are 18 and 6 percent, respectively; and the long-run ones are 27 and 9 percent, respectively. In addition, the environmental pollution elasticities of maritime transportation are three times of the air transportation ones.

Table III shows the estimation results of the economic growth model. In this model, all coefficients are again statistically significant. The coefficients indicate that the per capita GDP is inelastic with respect to maritime and air transportation modes and trade volume both in the short and long run. The short-run elasticities of per capita GDP with respect to maritime and air transportation are 5 and 10 percent, respectively; and the long-run ones are 12 and 25 percent, respectively. As a result, the elasticities of economic growth, denoted by per capita GDP, with respect to air transportation are twice as those of the maritime transportation.

Table IV. Estimated elasticities of environmental pollution and economic growth in the short and long run

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM</td>
<td>0.18</td>
<td>4.75</td>
<td>0.00</td>
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<tr>
<td>LA</td>
<td>0.06</td>
<td>1.69</td>
<td>0.10</td>
</tr>
<tr>
<td>LY</td>
<td>0.24</td>
<td>2.30</td>
<td>0.02</td>
</tr>
<tr>
<td>$\text{LCO}_{2t-1}$</td>
<td>0.35</td>
<td>3.09</td>
<td>0.00</td>
</tr>
<tr>
<td>$\alpha_1/\alpha_4$</td>
<td>0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha_2/\alpha_4$</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha_3/\alpha_4$</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ findings

Table III. Results of the GDP model estimation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.01</td>
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<td>LA</td>
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<td>LTR</td>
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<td>$\text{LY}_{t-1}$</td>
<td>0.60</td>
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<tr>
<td>$\beta_{1}-\beta_4$</td>
<td>0.12</td>
<td></td>
<td></td>
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<tr>
<td>$\beta_{2}-\beta_4$</td>
<td>0.25</td>
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<td></td>
</tr>
<tr>
<td>$\beta_{3}-\beta_4$</td>
<td>0.37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ findings

Table IV. Estimated elasticities of environmental pollution and economic growth in the short and long run

<table>
<thead>
<tr>
<th>Period</th>
<th>Environmental pollution</th>
<th>Economic growth</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Short run</td>
<td>Long run</td>
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<tr>
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<td>LA</td>
<td>0.06</td>
<td>0.09</td>
</tr>
<tr>
<td>LY</td>
<td>0.24</td>
<td>0.36</td>
</tr>
<tr>
<td>LTR</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>

Source: Authors’ findings

5. Discussion

Based on Table IV, the maritime transportation is more pollutant than the air one. The resulted elasticities in Table IV suggest that the maritime transportation is more pollutant than it would be economically beneficial. Air transportation, however, generates...
more economic benefits with lower environmental contaminants. These results originate from the higher investment in the maritime infrastructure in comparison with the air one, leaving low scope for the investment in the aviation mode.

Not only the long-run elasticities confirm the above-mentioned claims, but also the short run ones provide us with the evidence for the selection of air rather than maritime transportation, since the former mode is a cleaner and economic choice for developing transportation network in Iran. The geographical position of Iran is another evidence for this suggestion, since the majority of the country has no direct access to the sea transportation, which can offer the capacity for more growth in comparison with the air transportation.

Certainly, the above-mentioned discussion does not mean ignoring investment in maritime transportation; but rather, it gives a comparative analysis between maritime and air transportation modes. In another word, the air transportation has higher priority for investment and development, compared with the maritime one. However, the policy makers are recommended to reform the infrastructure of maritime transportation to make it more consistent with the environment and economic aspects.

6. Conclusion
This study compared the environmental and economic effects of maritime and air transportation in Iran.

Using econometric methodology, it employed two log-linear models to estimate the environmental pollution and economic growth elasticities of maritime and air transportation in the short and long run in Iran during 1978–2012. The data were derived from the Central Bank of Iran and the World Bank.

The results show the higher maritime transportation elasticities of environmental pollution and lower elasticities of the economic growth, compared with the air transportation. Given the results, it is implied that the maritime transportation is more pollutant and less productive in Iran, in comparison with the air transportation.

The policymakers are advised to improve the infrastructure of maritime transportation from both the environmental and economic point of views. The air transportation is a cleaner and more beneficial alternative for development as a public transportation in Iran, where geography offers less capacity for selecting the maritime transport as a widespread transportation mode. Furthermore, policy makers can provide the air transportation industry with more investment to achieve its goals.

For future research, it is recommended to analyze comparatively the four modes of transportation, adding the road and rail transportation. It clears the way for revealing the best alternative mode of transportation for inclusive development in Iran.

References


### Appendix

<table>
<thead>
<tr>
<th>Year</th>
<th>LCO₂</th>
<th>LY</th>
<th>LM</th>
<th>LTR</th>
<th>LA</th>
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<td>3.822</td>
<td>-6.637</td>
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<td>7.689</td>
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<td>-6.262</td>
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<td>3.072</td>
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<tr>
<td>1990</td>
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<td>-0.973</td>
<td>3.613</td>
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<td>1991</td>
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<td>-0.861</td>
<td>3.789</td>
<td>-6.711</td>
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<tr>
<td>1992</td>
<td>1.371</td>
<td>7.806</td>
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#### Table AI.
Data used in the econometric models

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Understanding high-quality development of marine economy in China: a literature review

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Abstract
Purpose – High-quality development of marine economy is a new concept put forward in response to the current national strategy in China. The purpose of this paper is to thoroughly understand the connotation and significance of high-quality development of marine economy through literature review, and further analyze the prospects for further research.

Design/methodology/approach – The authors first use the information visualization technology of CiteSpace to present a systematic review of the published literature from 2010 to 2019. Then, the authors analyze the researches on high-quality development of marine economy in terms of connotation, evaluation dimension, development path and guarantee mechanism.

Findings – Analysis results show that there is still insufficient understanding of the differences and links between the high-quality development of marine economy and the construction of marine power, intelligent ocean and transparent ocean.

Originality/value – Based on a thorough understanding of the subject, this paper puts forward the direction of further research on evaluation index system, path design scheme and policy system construction for high-quality development of marine economy.

Keywords Knowledge mapping, CiteSpace, Marine economy, High-quality development

Paper type Literature review

1. Introduction

Marine economy occupies an extremely important position in China’s economy. In 2018, the gross marine product reached RMB8.3 trillion, accounting for nearly 10 percent of GDP. The contribution rate of marine economy to the whole national economic growth was nearly 10 percent. The employment rate of marine economy reached 36.84m people and the employment rate of people involved in the sea was nearly 10 percent. Wang Hong, Director General of the State Oceanic Administration, explained that the marine economy was showing good development momentum with three 10 percent of the total. The rapid development of marine economy has become a new driving force for the development of national economy, but there are still many problems, e.g., capital-driven development model, low-end domestic demand, rough processing of consumer markets, small contribution rate and coefficient of technological progress, obvious differences in the long-term and short-term effects of economic policies, the lack of long-term impact mechanism of internal
development motivation, etc. The exchange of develop mode has become the top priority of China's marine economic development and even national economic development.

High-quality development of marine economy is the goal of the transformation of the mode of marine economic development, and also the means to realize the transformation from a large marine resource country to a powerful marine economic country. China leaders have put forward guiding opinions on the high-quality development of marine economy. In May 2017, the National Development and Reform Commission and the State Oceanic Administration issued the 13th Five-Year Plan for National Marine Economic Development (Open Edition). Guided by the current problems and needs of China's marine economic development, they established a global outlook on the distribution of marine economy. In January 2018, the National Ocean Work Conference put forward clear requirements for accelerating high-quality development of marine economy. On March 2018, general secretary Xi Jinping took part in the deliberations of the Shandong delegation at the 13th session of the National People’s Congress, pointing out:

[...]

A profound understanding of the connotation, dimensions and characteristics of high-quality development of marine economy is of great significance to the realization of the goal of building a powerful marine country.

In this study, we aim to analyze the researches on marine economy development based on online databases and with the use of scientific knowledge mapping software. This review includes the systematic analysis of keywords about marine economy in the literature. The aim of this review is to improve the understanding of high-quality development of marine economy, point out the insufficiency in current research and put forward further research directions on this topic.

2. Data collection and analysis method

The ISI Web of Science (WOS) database and Chinese National Knowledge Infrastructure (CNKI) database provide a guarantee for the reliability of raw data in visual analysis. Moreover, the search query provided by the institute accurate data acquisition. Here, the search criteria are “Subject: (marine or coastal or ocean) and (economy or industry)” for WOS and “Subject: (marine economy or marine industry) and high-quality development)” for CNKI. To cover current researches of this subject, the retrieval time span is set from 2010 to 2019. After screening, piece of data is downloaded as a full-record text format. The valid publications in total are 1,613 for WOS and 2,295 for CNKI, respectively.

In this study, CiteSpace is selected as the visualization analysis software. Knowledge map generated by CiteSpace is one of the most recognized technologies in the International Knowledge Metrology area (Chen, 2006; Chen et al., 2010). CiteSpace has widely been used in many fields such as information science, computer science and so on. It can realize the graphic expression of knowledge frameworks, structures, interactions, cross-overs, derivations and other internal links. However, CiteSpace can only outline the clue of the whole research field and not extract in-depth literature details. Therefore, we performed critical reading of the relevant literature to clarify the focus topics and frontiers of our subject.

3. Literature analysis based on CiteSpace

3.1 WOS literature analysis

Keywords are the core point of a paper and a high generalization of the topic. Therefore, keyword analysis in a certain field of the literature is helpful to find the research hotspots in this field. First, we import literature data from WOS into CiteSpace software. Then, set the time
span is 2010–2019, and the length of a single time partition is 1, the source of clustering words is title, abstract, author keywords and keywords, clustering word base is burst terms, node type is keyword, which extracts 50 keywords with the highest cited frequency in each time zone. Finally, run the software and keyword maps based on WOS data sets are generated as shown in Figure 1. In Figure 1, there are 450 nodes, 1,534 connections and the network density is 0.0152. The keywords with higher frequency are shown as larger nodes in the figure.

As can be seen from Figure 1, the biggest key node is “Management,” which mainly develops in four directions: Fishery, Marine Protected Area, Biodiversity and Sustainable Development. Other import key nodes include “Conservation,” “Climate Change,” “Impact,” “Sustainability,” “Environment,” “Ecosystem Service” and so on. Obviously, current researches on marine economic development focus on the management of the conservation of marine ecological environment. Marine industry pays more attention to the sustainable development. From the perspective of research methods, there is a strong trend of interdisciplinary.

Further analysis of the relevant literature shows that international scholars mainly interpret the connotation of high-quality economic development from the comparison of quantity and quality of economic growth, the relationship between economic growth and social welfare, and sustainable economic development. Energy efficiency and environmental pollution in marine economic development are also discussed. Relevant studies mainly focus on the establishment of green modernization, green growth performance and environmental performance growth index. For example, Zapelloni et al. (2019) discussed the sustainable production solutions of marine equipment under the circular economy, and emphasized the importance of sustainable development. Pioch et al. (2011) put forward the measurement criteria based on ecological, social and economic interests. Xia et al. (2014) made an analysis on the development of marine renewable energy industry, and found that the development of this industry is conducive to optimizing the development structure and improving the marine economy. Liu and Cao (2018) focused on the impact of marine tourism on the marine economy and studied the correlation between them. Natarajan and Gujja (2011) pointed out that developing countries could bypass high-pollution and low-efficiency production technologies and achieve low-carbon development through energy switching.

Figure 1.
The keywords of marine economy literature from WOS (2010–2019)
Melendez-Ortiz (2011) found that effective international trade management can greatly promote the development of global green economy. DeSombre (2011) demonstrated the important role of international environmental organizations in the development of green economy. In terms of theoretical basic research, Kildow and McIlgorn (2010) pointed out that the current marine economy and marine environment are facing many problems, and tried to find effective methods to study the discordant development between them.

3.2 CNKI literature analysis

Import literature data from CNKI and set parameters as described in Section 3.1. We can get 334 nodes and 926 connections by CiteSpace as shown in Figure 2. The network density is 0.0167.

From Figure 2, the biggest key nodes are “High-quality development,” “Marine economy” and “Marine industry.” Main directions for high-quality development include “Modern economy system,” “New development concept,” “Innovation drive,” “Structural reform of supply-side” and so on. It implies that current researches focus on the understanding of high quality and how to realize high quality. Main directions for marine industry and marine economy include “Economy,” “Marine resource,” “Blue economic zone,” “Coordination of land and sea,” etc. Current researches on such subjects focus on the interaction between marine industry development and related areas, such as marine culture, marine resource, innovation and so on. The main method is case study of marine economic zone. However, from the relationship between high quality and marine economy, scholars seldom consider the particularity of marine economy in their researches on high-quality development.

Further analysis of the relevant literature shows that domestic scholars mainly interpret the connotation of high-quality economic development of marine economy from the background of times, such as five development concepts, supply-side structural reform and the transformation of new and old kinetic energy and so on. High-quality development is understood as a profound change in China’s economic development model. For example, Chao and Xue (2018) and Jin (2018) understand the concept of high-quality economic development from the perspective of the new normal economy. Ren (2018) and Chen and Chen (2018) understand the concept of high-quality economic development from the perspective of social contradiction transformation and five development concepts. Zhang and Zhao (2019) and

Figure 2.
The keywords of marine economy literature from CNKI (2010–2019)
4. Conclusions and prospects
This paper analyzes related researches on high-quality development of marine economy based on the knowledge map of CiteSpace. Analysis results show that scholars mainly study current situation and countermeasures from a macro-perspective. Research topics focus on related industries and activities of marine economy, mainly involving the contents of management, economics and ecology. A multi-disciplinary research framework system in this area has not yet been established, and needs more in-depth study.

4.1 Concept and characteristics
Since the concept of high-quality development of marine economy was put forward, scholars have done a lot of research on it, and preliminarily discussed the connotation and inherent requirements. Current studies have interpreted the high-quality development of marine economy from multiple dimensions, mainly involving the utilization of marine resources, ecological optimization, green development and other aspects. Overall, they have a profound interpretation of national policies, but the scientific connotation and attributes of the high-quality development of marine economy remain at the policy level. In terms of internal requirements, the main concerns of existing researches are the adjustment of marine industrial structure, the transformation of new and old kinetic energy, marine ecological protection and marine open economy, etc. However, the research contents are mostly from a macro-perspective, and rarely involve how to achieve the problem.

Further research should pay more attention to the characteristics of China’s marine economic development in the period of deep adjustment from high speed to high quality, and guided by the five development concepts. High-quality development aims at achieving the high efficiency, high efficiency, co-ordination, innovation, sustainability, stability, security and sharing of marine economic development. Researchers should deeply interpret the connotation, characteristics and extension of high-quality marine economic development and identify marine economy. Relationships between high-quality development and the construction of green economy, intelligent ocean, digital ocean, transparent ocean and marine power are also need to be discussed. The functions and objectives of high-quality development of marine economy should be identified. The criteria for evaluating high-quality development of marine economy should be summarized from micro, medium and macro levels.

4.2 Fine evaluation
Research on fine evaluation of high-quality development of marine economy has not been found yet. Current researches mainly focus on the comprehensive evaluation of marine economic development and high-quality development. The comprehensive evaluation of
marine economy mainly focuses on four aspects: the evaluation of comprehensive strength of marine economy, the evaluation of innovation driving capacity of marine economy, the evaluation of sustainable development capacity of marine economy and the evaluation of marine economic performance. At present, domestic scholars pay more attention to the indicators of sustainable development and ecological environment in the evaluation of marine economic development. Researches on the evaluation index system of marine economic development do not take into account the factors of high-quality economic development, while researches on the evaluation index system of high-quality economic development do not consider the special characteristics of marine field. Therefore, in view of the particularity of marine economic development, it is urgent to conduct in-depth study on the fine evaluation of high-quality development of marine economy.

4.3 Path choice
Research into high-quality development path of marine economy are relatively extensive. From the perspective of China’s overall development path, they mainly focus on developing new marine industries, enhancing marine scientific and technological innovation capacity, increasing financial support for offshore enterprises, protecting marine ecological environment and balancing regional marine economic development. From the perspective of China’s regional development path, the main concerns are to cultivate high-tech industries, foster marine industrial clusters, coordinate the development of land and sea and enhance the ability of scientific and technological innovation. However, the existing literature mostly stays in macro-policy and macro-industry. In order to achieve high-quality development of marine economy, we need to consider the “micro-meso-macro” three-dimensional development path of marine economy driven by “market pull-government push” and explore the specific path choice (Guan et al., 2017).

4.4 Policy mechanism
Research into marine economic development security mechanism mainly involves policy guarantee and financial service guarantee. From the perspective of existing policy guarantee mechanism, the State Council, the Ministry of Land and Resources and the State Oceanic Administration have issued a series of important policies, decisions and measures, which fully demonstrate the importance of the state to the economic and strategic oceans. From the perspective of existing service support, whether it is policy-based financial support or commercial financial support, the support role in high-quality development of marine economy is becoming increasingly obvious. However, the existing literature has not yet generated systematic theoretical results, which cannot effectively support the practice of promoting high-quality development of marine economy, and lacks the institutional design of “concept-system-technology.” Therefore, it is urgent to analyze and innovate the guarantee mechanism for promoting high-quality development of marine economy. Such guarantee mechanism and service system should promote the sustainable, stable and healthy development of marine economy.

References


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