Energy Efficiency Measurement Method of Operating Ship Based on Data Mining

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Abstract. Energy conservation in ship operation has become an important measure to reduce global greenhouse gas emissions. Therefore, it is necessary to carry out effective measurement of the energy efficiency of operating ships, so as to lay a foundation for their energy consumption. Based on this, this study designed a measurement method of energy efficiency of operating ships based on data mining. On the basis of analyzing the energy efficiency characteristics of operating ships, the paper analyzes the vessel resistance and the transfer of energy demand. Based on this, the energy efficiency measurement algorithm of operating ships is designed. By standardizing the energy consumption value of ships during navigation, the energy efficiency conversion of operating ships can be suppressed and utilized to avoid excessive energy consumption of ships during navigation and effectively control the Greenhouse gas emissions during navigation.

Keywords: Data mining, To operate ships, Energy efficiency measurement, Energy demand transfer.

1. Introduction
Shipping industry is a high energy consumption industry, ship fuel is easy to produce a lot of carbon dioxide and other greenhouse gases. With the development of the world shipping business, shipping companies add more new routes, and the greenhouse gas emissions of ships are bound to increase significantly [1]. In order to solve the above problems, this study designed a measurement method of energy efficiency of operating ships based on data mining.

The Energy Efficiency Operating Index is an index published by the International Maritime Organization to measure the energy efficiency of ships [2]. This paper makes an in-depth analysis of the energy efficiency data of operating ships from the perspective of data mining. From the perspective of data mining index connotation, the compilation principle of energy efficiency measurement of operating ships is based on carbon dioxide emission of unit transport turnover. Based on the calculation formula of data mining theory, it is pointed out that the main factors affecting the measurement of ship energy efficiency are ship type, ship type and operating factors. Then, through the sensitivity analysis of operating factors, it is shown that the most significant way to clearly reduce the energy efficiency of operating ships is to improve the energy efficiency, that is, to improve the full load rate. Based on this, the optimal sailing speed of a ship under a certain condition is calculated by
using the data mining formula of turnover rate per unit time. The experimental results show that the energy efficiency measurement method based on data mining can lay a foundation for energy conservation of operating ships.

2. Energy efficiency measurement method for operating ships

2.1. Energy efficiency characteristics of operating ships

The characteristic structure of energy efficiency of operating ships is shown in Figure 1.

![Energy efficiency characteristic structure of operating ships](image_url)

**Figure 1.** Energy efficiency characteristic structure of operating ships

Energy conservation and emission reduction has always been one of the key areas of ship energy conservation research. Energy conservation is also an important content adopted by the International Maritime Organization. Therefore, it is necessary to establish a corresponding shipboard energy efficiency information acquisition system to realize the acquisition and transmission of ship navigation data, which provides data basis for analyzing the relationship between ship operation behavior, navigation conditions and ship discharge [3-4]. At the same time, the crew should formulate and implement energy saving measures according to the characteristics of the ship and navigation [5]. After the redefinition of the energy efficiency factor list, energy efficiency measures need to be re-evaluated according to the energy efficiency factor List in order to select and determine new energy efficiency factors in the next round of the energy efficiency management plan.

Setting energy efficiency targets is the final step in the planning phase. Each enterprise can set energy efficiency goals and targets in a specific period according to energy efficiency standards and benchmarks. These goals and targets must be measurable and easy to understand. Energy conservation must comply with international laws and regulations and the relevant laws of the flag state [6]. Energy efficiency monitoring tools and methods are used to monitor energy efficiency targets. The energy efficiency index of ship operation is an internationally determined tool, which can be used as the main monitoring tool to obtain the energy efficiency value of ships or fleets. In addition to 5‰ of the fuel consumption, enterprises can also obtain 5‰ of the annual fuel consumption. The influence of ship navigation environment factors on ship performance and state is multifaceted, but the knowledge content of ship navigation environment is scattered, lack of sharing and transmission, the influence
mechanism is complex, and the systematic research on the influence of ship navigation environment is lacking [7]. According to the characteristics of marine energy saving, the marine energy saving research system is designed, and the data acquisition, transmission, storage strategy and analysis method of marine energy saving are studied. Based on the ship energy-saving data, the influence of random environmental factors on ship energy-saving is analyzed, and the influence of environmental factors on ship energy-saving is studied, and the ship energy-saving index is included in the route planning.

2.2. Analysis of ship resistance and energy demand transfer
The essence of data mining in ship energy-saving transformation is to improve the energy utilization rate of ships. Finally, how to reduce the fuel consumption of ships. Marine fuel consumption can be divided into main engine, generator, boiler, etc. In the energy consumption, the main engine consumption accounts for the largest proportion, and the consumption of other equipment can basically be used as a function of time to conduct preliminary energy efficiency analysis, so the host consumption is the focus of this paper [8]. Push the boat forward or backward, forward or backward. Under normal navigation conditions, the thrust is used to overcome the hull resistance, that is, the torque of the propeller is equal to that provided by the main engine [9]. However, only in the ideal state, the actual navigation behavior of the ship will be more complex. The change of resistance is caused by the change of navigation environment such as wind, wave, current and deep water, and the change of ship condition when the bottom surface is polluted. Therefore, ship speed, propeller and main engine conditions will change, which will affect the energy efficiency of the ship. The relationship between ship resistance and energy demand transfer is shown in Figure 2.

Based on the analysis of the ship's sailing state at the same speed, this study considers that the ship's fuel consumption is a molecular item in the data mining calculation formula, which is mainly composed of fuel consumption of main engine and fuel consumption of auxiliary engine. More importantly, it can successfully complete the ship's mechanical and electrical equipment energy-saving performance test. Based on this, formula (1) can be used to maximize the effectiveness of the work efficiency test:

**Fig 2. Relationship between ship resistance and energy demand transfer**
1. Absolute impact

\[ X_q = \begin{cases} 
1, & \lambda > 0 < 1 \\
0, & \text{Not at all}
\end{cases} \] \hspace{1cm} (1)

In formula (1), \( \lambda \) is corresponding to the different life stages of detection influence degree. According to the degree of impact, it can be divided into three categories: general impact, serious impact and non-general impact, and the quantitative values are 0.2, 0.4, 0.6 and 0.8, respectively [10-11]. The shorter the life cycle of marine mechanical and electrical equipment is, the shorter the test time is and the lower the occupancy rate of test resources required, thus ensuring the smooth completion of the test task. The formula is as follows:

\[ Y_q = X_q - 1/s \] \hspace{1cm} (2)

In formula (2), \( s \) represents the time spent in detecting the operating efficiency, which is generated according to the corresponding operating efficiency detection functions of the equipment in different life stages.

Since the energy efficiency test is usually conducted every 100 hours, the priority is given to time, that is, the success or failure of the energy efficiency test in operation will be affected by the test results. When the main engine of a ship leaves the factory, the fuel consumption of the main engine is set as the reference ratio \( g / \text{kWh} \), that is, under a certain maintenance level, the fuel consumption of the main engine can be calculated according to the output power and operation time, and the fuel consumption generated by the main engine is taken as the power, and the power of the main engine is absorbed through the shafting to promote the propeller to work [12]. The ratio of the output power of the propeller to the power of the main engine is called the efficiency of the propeller \( \eta_p \). Then we can get:

\[ \eta_p = \frac{F_p V_p}{M_p 2\pi n_p} \] \hspace{1cm} (3)

Assuming that the ship is advancing at \( v \) speed, the main engine speed is \( n \), and the output power is \( P_s \), the main engine drives the propeller to rotate to generate thrust, so as to overcome the resistance to \( r \) when the ship is advancing at \( v \) speed, the following steps can be analyzed for the transmission system [13]. The shaft transmission efficiency \( \eta_s \) is the ratio of the main engine power received by the propeller to the total power

\[ \eta_s = P_{Db} / P_s \eta_p \] \hspace{1cm} (4)

If the main engine is directly connected to the propeller without reduction gear, then \( \eta_s \) can be taken as 0.97 for medium-sized ships and 0.98 for tail ships. If there is a deceleration device, the efficiency of the deceleration device should also be included. Where \( \eta_G \) is generally 0.96, which can be adjusted according to the actual situation

\[ \eta_s \eta_G = P_{Db} / P_s \] \hspace{1cm} (5)
Both $\eta_s$ and $\eta_G$ are not affected by the hydrodynamic performance of the hull and propeller, but are mechanical transfer efficiency. The ratio of propeller effective power $P_E$ to $P_{DB}$ received by propeller is:

$$\eta_D = \frac{P_E}{P_{DB}}$$  \hspace{1cm} (6)

The composition of propeller efficiency can be divided into tail propeller efficiency (including relative rotation efficiency and propeller boiling water efficiency) and hull efficiency (reflecting the interaction between propeller and propeller). It can be seen from the above analysis that the hull, propeller and main engine can be connected with each other. When $r$ is set at $v$, the relationship between ship's total power (fuel consumption) and ship's resistance can be expressed as follows: first, estimate the wake coefficient and thrust coefficient at the speed, and then calculate the thrust at the speed [14]. On this basis, combined with the shafting transmission efficiency, propeller speed and torque, the torque and received power of the propeller tail are calculated. According to the oil consumption data and ship speed, the ship resistance is reversely processed to obtain the required main engine power, and the ship resistance is analyzed.

2.3. Energy efficiency measurement algorithm for operating ships

Further using data mining algorithm, it is necessary to establish the emission standard authoritative statistical method, so as to optimize the energy efficiency measurement algorithm of the operating ship. In the process of energy efficiency measurement of ship navigation, the emission of carbon dioxide is an important problem. It is obviously not correct to judge the quality of the atmosphere by using only the carbon dioxide emissions. For example, we can't think of cars as environmentally friendly vehicles because they emit less carbon dioxide than ships [15]. The carbon dioxide emission industry is divided into two categories: static (such as electricity) and dynamic (such as transportation). The calculation formula is formulated according to the enterprise accounting and reporting standards stipulated in the greenhouse gas emission agreement. For the transportation industry, the following formula of carbon dioxide efficiency is given:

$$E_{CO_2} = \frac{m_{CO_2}}{m_{cargo} \times D}$$  \hspace{1cm} (7)

Among them, $m_{cargo}$ is the energy efficiency of cargo transportation volume of cargo operation ships, unit: t; $D$ is the cargo transportation distance of the operating ship, unit: km; $m_{CO_2}$ is the energy efficiency emission of corresponding cargo turnover of the operating ship, unit: g; $m_{cargo} \times D$ is the energy efficiency turnover of ship transportation. The traffic flow index not only reflects the size of traffic flow, but also reflects the influencing factors of traffic flow. Compared with the pure transport volume index, it can reflect the effect of transport production more comprehensively. Therefore, the internationally accepted measure of the environmental benefits of the mode of transport is measured by the carbon dioxide emissions per unit of transport turnover. The details are shown in the following table:
Table. 1 types of energy consumption and emission of operating ships in navigation

| Type                      | Characteristic                                      | Accuracy (grade) | Applicable liquid | Mode of transportation |
|---------------------------|-----------------------------------------------------|------------------|-------------------|------------------------|
| Rotor type flowmeter      | Lumbar whorl Large volume, bulky,                   | 0.1-0.5          | Clean liquid and oil | International shipping |
|                           | large pressure loss and vibration                   |                  |                   |                        |
| Elliptical gear           | The outlet pipe has pulsation and high precision    | 0.2-1.0          | Clean liquid and oil | Domestic shipping and fishery |
| Gear                      | Small size, light weight and small vibration        | 0.1-0.5          | Fuel              |                        |
| Double rotor              | Stable operation, no pulsation at the outlet,       | 0.1-0.5          | Oil               | Other energy industries |
|                           | complex structure and horizontal installation       |                  |                   | Other transportation   |
| Piston flowmeter scraper flowmeter | Reciprocating Four piston flow is relatively stable; Smooth operation | 0.2-0.3          | Clean liquid and oil | -                      |
| Rotary type               | No pulsation and low noise                          | 0.2-0.3          | Clean liquid and oil | Other industries       |

On the premise of maximizing energy efficiency, relevant laws and regulations should be formulated to avoid transferring some goods to other transportation modes due to complicated regulations. This not only increases global carbon dioxide emissions, but also causes losses. Using BSR index, it is easy to calculate the carbon dioxide emission when transporting goods. In addition to the ship, only need to know which ship is used to carry the goods. Calculate the BSR index of the route and send the energy efficiency information. BSR index has never been used for energy saving control index of single ship. This index is only applicable to container ships, but also to ships in the same route if the ship is fully loaded. So, there are the following definitions:

$$BSR = \frac{\sum_i FC_i \times C_{fi}}{M_{cargo} \times D}$$ \hspace{1cm} (8)

Among these indicators, $i$ is fuel type; $FC_i$ is total fuel consumption; $C_{fi}$ is carbon dioxide emission coefficient; $M_{cargo}$ is the maximum (full) cargo capacity in TEU; $D$ is ship mileage, unit: nm. And then the segment variable $j$ is introduced to obtain the data mining value of ship energy efficiency operation index. The specific algorithm is as follows:

$$EEOI_{voyage} = \frac{\sum_j \sum_i (FC_{ij} \times C_{fi})}{\sum_j (m_{arg.o./j} \times D_j)}$$ \hspace{1cm} (9)

The mass conversion coefficient $C$ of carbon dioxide is a dimensionless conversion coefficient, which reflects the conversion relationship between carbon content of fuel, CO$_2$ emission (in gram) and $CF$ value.
Table. 2 conversion coefficient of energy consumption quality

| Fuel type                  | Reference | Carbon content | $C_2(t\text{CO}_2/\text{- fuel})$ |
|----------------------------|-----------|----------------|----------------------------------|
| Diesel / gasoline ISO 8217| 0.857     | 3.2060         |
| LFO (light oil) ISO 8217  | 0.860     | 3.1514         |
| Heavy oil (HFO) ISO 8217  | 0.850     | 3.1144         |
| Liquefied petroleum gas (LPG) butane | 0.819 | 3.0650 |
| Liquefied hot gas (LNG) Pentane | 0.750 | 2.7500 |

According to the calculation formula of data collection, the impact of data collection results is mainly reflected in four aspects, namely fuel consumption, fuel type, fuel transportation volume and voyage mileage, which can be attributed to transportation turnover.

Through management and scheduling to optimize their own transport turnover, and for a single ship, it can be adjusted by ballast water, so as to increase the weight of cargo. From the point of view of data collection, to improve the efficiency of ship energy utilization is to improve the efficiency of ship energy consumption, and the key to improve the efficiency of ship energy consumption is to reduce the energy consumption of ships. In order to further overcome the shortcomings of the existing indicators, a new alternative index of ship energy efficiency is proposed. In the process of establishing the EEPI index, because the index compulsorily excludes the dependence on the actual loading state of the ship, there is no commercial sensitivity problem, that is, EEPI overcomes the biggest defect of data mining index. However, the consistency between EEPI index and data mining index and the deviation from cDIST index need to be further tested. In order to fully verify the consistency between EEPI and data mining indicators, horizontal dimension and vertical dimension should be considered. The transverse vector refers to the consistency among the classes, that is, the energy-saving performance of the same ship group in the same observation period is sorted by using these two indexes, and the consistent ranking results are obtained. Both of them refer to the energy change rate observed at the same time point in the same period, and both refer to the energy change rate observed in the same period.

Marine fuel consumption can be used as a function of the last part of the figure, that is, fuel consumption, thrust, speed, working time, auxiliary fuel consumption. When the ship sails under the stable wind load condition, many factors are considered under the ideal navigation condition; the ship considers more factors under the ideal navigation condition, and the influence of wind is greater; the departure port and the destination port only stop. The estimation formula of ship data mining under ideal conditions is given.

$$EEOI' = \frac{F_M(P) \times t_s + (F_A + F_B) \times (t_s + t_p)}{DW \times R \times d} \times 3.1144 \times 10^{-3}$$

(10)

Where:

$$F_M(P) \propto P = a \times P + b$$

(11)

$$P = K \times \Delta^{2/3} \times V_s^3$$

(12)

$$\Delta = LW + DW$$

(13)

$$t_s = \frac{D}{V_s}$$

(14)
Among them, \( F_{\text{m}}(P) \) is a linear function of the engine's fuel consumption per hour, \( P \) is the fuel consumption per hour of the main engine, \( a \) is the fuel consumption of the main engine, \( B \) is the fuel consumption of the main engine, \( K \) is the comprehensive coefficient constant; \( LW \) is the fuel consumption of the empty ship, \( DW \) is the actual loading capacity of the ship, \( V \) is the speed, \( F_{\text{a}} \) is the fuel consumption of the auxiliary engine, \( F_{\text{b}} \) is the fuel consumption of the boilier, \( t_s \) is the sailing time of the ship, \( t_p \) is the berthing time, and \( DW_d \) is the designed fuel consumption of the ship. \( R \) is the loading capacity and \( d \) is the departure time. The fuel consumption and man hour consumption of auxiliary equipment can be estimated according to the type of equipment and maintenance. The output end of the main engine is connected with the reduction gear by using the fixed pitch propeller, so that the propeller speed is directly proportional to the main engine speed. The propeller speed can be obtained by monitoring the main engine speed. The thrust of the hull is difficult to determine. There are many factors affecting ship thrust, such as speed, descent speed, visceral condition, draft and weather. Therefore, according to the research status at home and abroad, the relationship between ship fuel consumption and ship operation behavior is discussed by using statistical analysis method. Using the data-oriented method, this paper analyzes the influence of various factors on ship energy efficiency, and obtains the rules of ship energy efficiency, which provides the basis for formulating the ship energy efficiency management plan. This paper analyzes and selects the factors that affect the energy consumption of ships, establishes the data acquisition subsystem, and uses the sensing technology and other information collection means to collect data, which lays the foundation for the research of ship energy saving. The data transmission subsystem and data analysis subsystem choose the appropriate communication scheme according to the different communication modes on shore, combined with the environmental conditions and ship characteristics. Through the design of database architecture, the data analysis subsystem helps the next step of knowledge discovery and data mining, reveals the relationship between data through regression analysis and principal component analysis, analyzes the internal law of data, provides theoretical and technical support for the optimization of ship operation behavior, and finally provides the basis for the formulation and implementation of ship energy efficiency management scheme.

3. Analysis of experimental results

In order to verify the energy efficiency measurement methods of operating ships based on data mining, a detection and control method of energy efficiency measurement was constructed based on matlab7.0 environment, network simulation software as information transmission simulator, and C++ as network protocol. The main engine fuel consumption, that is, if there is only one reading per minute of fuel consumption, the sensor error should be less than 100 g. according to the speed, the proficient stage can be divided into two categories: three levels and five sections. According to the definition of data mining, this parameter is applicable to all transport ships. Based on this, the standard setting of experimental parameters is carried out, as shown in the following table:

Based on the comparative test of energy and material energy consumption of operating ships, the ship was taken as the research object to illustrate the measurement of ship energy efficiency under ISO standard operation conditions.

Based on the test results, compared with the traditional methods, the energy efficiency measurement method of operating ships based on data mining proposed in this paper has higher accuracy in the actual application process, and further compares the detection of energy consumption conversion inhibition of different ship types.

Based on the test results shows that compared with traditional methods, this paper puts forward the operation of the ship's energy efficiency measurement method based on data mining of inhibition of ship conversion of energy consumption of different load conditions is obviously better than the traditional methods, which confirmed that the operation of the ship's energy efficiency measurement method of data mining in practical application process more effective.
To sum up, the energy efficiency measurement method based on data mining design in this paper can measure and control the energy efficiency of ships more accurately in the practical application process, and reduce the ship's seemingly loss to the greatest extent, so as to ensure the low-carbon operation effect of ships.

4. Conclusions
In the context of global reduction of greenhouse gas emissions and improvement of energy efficiency, it is necessary to enact legislation on ship energy efficiency. Based on this background environment, data mining technology is applied to optimize the energy efficiency measurement method of operating ships, analyze the operating efficiency and energy consumption conversion within the ship operating cycle, regulate the energy efficiency and displacement of ships, and ensure the navigation effect of ships. The experimental results show that the above energy efficiency measurement method can maintain high detection accuracy, effectively restrain energy consumption and discharge, and avoid the problem of excessive resource consumption.

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