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RESEARCH OF MONITORING CO_2 EMISSION FOR VESSELS BASED ON AIS INFORMATION

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ABSTRACT

To monitor the ships' CO2 emission in certain region in real time, a mathematical model for assessing ships' CO2 emission is established. The mathematical model establishes the relationship between the ships' CO2 emission and ships' data provided by Automatic Identification System located in a certain region, through analyzing computing methods of the ships' CO2 emission and oil consumption. According to the model, we could know the detailed number of a certain ship's CO2 emission and the total number of ships' CO2 emission in certain region for a period of time.

KEYWORDS

ship's CO2 emission, Monitoring, Fuel consumption, Automatic Identification System (AIS).

1. INTRODUCTION

With the rapid development of the shipping industry, a substantial increase in the number of ships results in the rise of marine CO_2 emissions. As one of the sources of greenhouse gases, marine CO_2 emissions have a huge impact on the global environment. According to the requirements of the Kyoto Protocol, developing countries began to undertake emission reduction obligations from 2012. According to highway and waterway transportation energy saving" Twelfth Five-Year "plan drafted by the Ministry of Transport, the ratio of ships' CO_2 emissions and traffic turnover in 2015 will fall by about 16% compared with 2005.

In recent years, there are a large number of studies on CO_2 emissions, such as COSCO energy efficiency management information systems & CO_2 emissions calculator and remote real-time monitoring system of ship fuel consumption. The former can report ship draft, daily energy consumption, ship remaining fuel, daily sailing distance, the distance off the destination, weather conditions, cargo tonnage to the company at regular time [1]. The latter acquires main engine fuel consumption, main engine revolution, main engine speed and so on through the terminal aboard in real-time and display the results which are computed by shipboard terminal or shore-based devices [2].

Due to the broad coverage area of shipborne AIS equipment, and the close relationship between AIS data and the ship CO_2 emissions, so it is available to use AIS data for ship CO_2 emissions statistical analysis.

2. RELATED CONCEPTS

2.1 CO2 emission factor

CO2 emission factor refers to the ratio of carbon dioxide emissions and fuel consumption. It depends on the carbon content of fuels and carbon oxidation rate, so the CO2 emission factors vary as the change of types of fuel and types of main engine.

2.2 Energy efficiency design index(EEDI)

EEDI is the abbreviation of the ship energy efficiency design index [3]. It refers to the carbon dioxide emissions generated by ships which sail under designed tonnage, which is an important indicator and should be considered while designing a ship. Proposing EEDI is aiming for controlling CO2 emissions of the shipping industry.

2.3 Energy efficiency operational indicator(EEOI)

EEOI is the abbreviation of the ship energy efficiency operational indicator. It refers to the carbon dioxide emissions generated by ships which sail under certain tonnage, computational formula is as follows [4]:

$$EEOI = \frac{\sum Q * CF}{\Delta * D} \qquad (1)$$

Where Q represents fuel consumption; CF represents the carbon dioxide emission factor. Δ represents ship tonnage, and D represents the ship sailed distances. The smaller value of EEOI is, the higher the energy efficiency of ships is.

3. ESTIMATED METHODS OF CO_2 EMISSION AND FUEL CONSUMPTION

3.1 Estimated methods of CO_2 emission

In the life cycle of the ship, its carbon emissions are mainly concentrated in the operation phase. What's more, the CO2 emissions in the operation phase depends mainly on ship's fuel consumption [5]. Therefore, the article summarizes the estimation method of CO2 emissions, including fuel consumption method and manual method [6, 7].

3.1.1 Relationship between CO2 emission and fuel consumption

Fuel consumption method estimates the amount of CO2 emissions through acquiring the amount of fuel consumed by the ship [8]. According to the IPCC manual, CO2 emission factors are in the following table corresponding to all kinds of fuels:

Table 1: CO_2 emission factors of ship fuels

Fuel type	Carbon content	carbon oxidation rate (%)	CO_2 emission factor
MDO	0.875	0.98	3.20
LFO	0.86	0.98	3.15
HFO	0.85	0.98	3.11

$$C = Q * CF \quad (2)$$

Where Q represents the amount of fuel during a period of time, and C represents ships' corresponding carbon dioxide emissions. The method is simple and practical; however, acquisition of ships' accurate fuel consumption is of great importance.

3.1.2 Manual for quantifying CO2 emission

Due to the impact of ship working conditions and ship type on the carbon oxidation rate of fuels, Manual method takes them into account:

$$C = \frac{p * Q * 44 * r}{12} \quad (3)$$

Where P represents carbon content factor of fuel, and r represents carbon oxidation rate. Manual method takes the sailing state of ship and the condition of main engine into account, which is adequate for calculating CO2 emissions for a single ship [9].

3.2 Estimated methods of fuel consumption

3.1.1 Relationship between fuel consumption and AIS information

The 《Navigation》 clarifies the relationship among fuel consumption, ship displacement, ship speed and ship voyage compiled by Guo Yu. The formula contacting ship fuel consumption, ship displacement and ship speed is as follows:

$$Q \propto \Delta^{2/3} * v^3 \quad (4)$$

The formula contacting ship fuel consumption, ship voyage and ship speed is as follows:

$$F \propto v^2 * D \quad (5)$$

From the equation (4) and (5), we can see positive correlation between ship fuel consumption and ship voyage, ship displacement, ship speed.

3.1.2 Computational methods of fuel consumption

The ship fuel consumptions are derived from main engine, auxiliary engines and boilers. According to statistics, they accounted for 87%, 11% and 2% correspondingly.

Ship fuel consumption for main engine can be obtained by Navy coefficient which is the conversion factor between ship main engine power, ship speed and ship displacement) is obtained:

$$F_M = a * P + b \quad (6)$$

$$P = \frac{\Delta^{2/3} * v^3}{c} \quad (7)$$

In the equation above, P represents the ship main engine power, C representing the Navy coefficient, F_M indicating the main engine fuel consumption, while both a and b are conversion factors for main engine fuel consumption and main engine power.

The ship fuel consumption for single voyage can be calculated through formula (8):

$$Q = (k * \Delta^{\frac{2}{3}} * V^3 + k_2) * \frac{D}{V} + (F_A + F_B) * (t_p + \frac{D}{V}) \quad (8)$$

The first portion of formula (8) show the main engine fuel consumption, and the second part shows the auxiliary and boiler fuel consumption. t_p represents the ship berthing time, while F_A and F_B represent the auxiliary and boiler fuel consumption respectively. k_1 and k_2 are constant, depending mainly on the ship main engine type.

4. EVALUATION MODEL OF CO_2 EMISSION

4.1 Analysis of CO_2 emission influence factor

Through the conversion between the equation (3) and (8), the relationship between the CO2 emissions and AIS information is established:

$$C = \frac{Q * P * r * 44}{12} = \frac{[k_1 * \Delta^{\frac{2}{3}} * V^2 * D + \frac{D(k_2 + F_A + F_B)}{V} + t_p(F_A + F_B)] * P * r * 44}{12} \quad (9)$$

The formula (9) shows the estimated value of ship carbon emissions for single voyage. Thus, we find speed, displacement, voyage and berthing time vary frequently with time, which are important CO_2 emissions factors.

4.1.1 Speed factor analysis

According to formula (9), the connection between ship energy efficiency operational index and ship speed is given in the formula (10):

$$EEOI = \frac{44\,\mathrm{Pr}}{12}[k_1 * \Delta^{-\frac{1}{3}} * v^2 + \frac{(F_A + F_B) * t_p}{D * \Delta} + \frac{F_A + F_B + k_2}{v * \Delta}] \quad (10)$$

Through analyzing formula (10), it shows that the larger the ship speed, the greater the main engine fuel consumption, but the ship sailing time is correspondingly shorter. So the fuel consumption is neither positive correlation with the ship speed, nor negative correlation with the ship speed. Thus, there is a particular economic speed which corresponds to each ship, which makes ship producing the lowest CO_2 emissions.

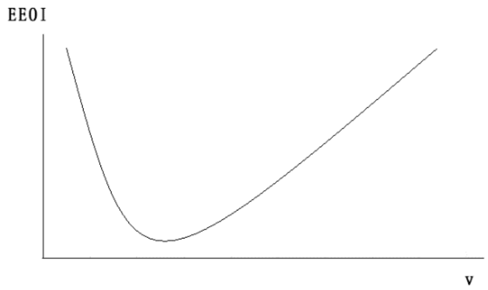

Figure 1: The relationship between CO2 emissions and ship speed

Ship speed can be acquired from AIS dynamic information at fixed period.

4.1.2 Displacement factor analysis

According to formula (9), the connection between ship energy efficiency operational index and ship displacement is given in formula (11):

$$EEOI = \frac{44\,\mathrm{Pr}}{12}\{k_1 * \Delta^{-\frac{1}{3}} * v^2 + \frac{1}{\Delta} * [\frac{k_2}{v} + (F_A + F_B) * (\frac{t_p}{D} + \frac{1}{v})]\} \quad (11)$$

For a particular voyage, keeping the speed, voyage and berthing time unchanged, the larger ship displacement, the corresponding ship energy efficiency operational index is smaller. Therefore, the ship CO_2 emissions are negatively correlated with ship displacement.

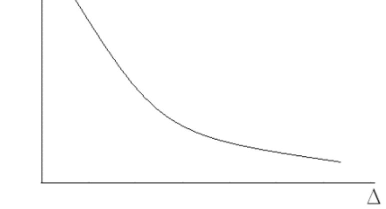

Figure 2: The relationship between CO_2 emissions and ship displacement

Ship displacement can not be derived directly from AIS information; however, it is available to count the ship voyage displacement by using the ship voyage draft and ship maximum draft and ship maximum deadweight (DWT). The ship maximum DWT can be converted from ship length (one of AIS static information).

4.1.3 Ship voyage factor analysis

According to formula (9), the connection between ship energy efficiency operational index and ship voyage is given in the formula (12):

$$EEOI = \frac{44\,\mathrm{Pr}}{12}\left(k_1 * \Delta^{-\frac{1}{3}} * v^2 + \frac{k_2+F_A+F_B}{\Delta * v} + \frac{(F_A+F_B)*t_p}{D*\Delta}\right) \tag{12}$$

For a particular voyage, keeping the speed, displacement and berthing time unchanged, the farther the ship navigates, the smaller the corresponding ship energy efficiency operational index is. Therefore, the ship CO2 emissions are negatively correlated with ship voyage.

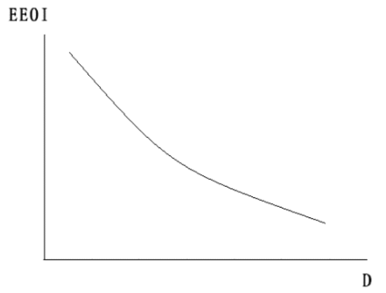

Figure 3: The relationship between CO2 emissions and ship voyage

Ship voyage can be acquired from AIS dynamic information at fixed period.

4.1.4 Ship layover time factor analysis

For a particular voyage, keeping the speed, displacement and berthing time unchanged, the longer the ship layover time, the bigger the corresponding ship energy efficiency operational index is. Therefore, the ship CO_2 emissions are positively correlated with ship layover time.

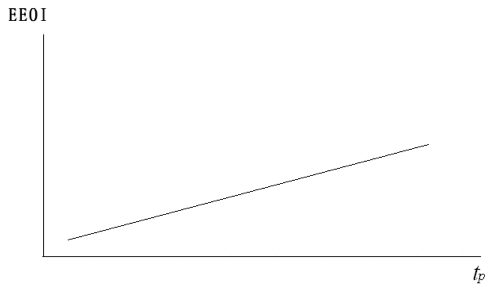

Figure 4: The relationship between CO2 emissions and ship layover time

Ship layover time can be acquired by data computing, which are obtained from AIS dynamic information.

4.2 Computational methods of CO_2 emission

The article proposes CO2 emission calculation methods according to the weight of each CO2 emissions factor.

4.2.1 Computational methods of CO2 emission for single ship

Connected with the analysis of CO_2 emissions influence factors, the formula (13) show the computational methods of CO_2 emission for single ship:

$$\sum_{i=1}^{m} EEOI = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} 44 Q_{ij} * P_j * r_j}{\sum_{i=1}^{m} 12\Delta_i * D_i} \tag{13}$$

$$= \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left\{44 P_j * r_j * \left[k_1 * \Delta^{\frac{2}{3}} * V^2 * D + \frac{D(k_2+F_A+F_B)}{V} + t_p(F_A+F_B)\right]_{ij}\right\}}{\sum_{i=1}^{m} 12\Delta_i * D}$$

Where i represents the serial number of ship voyage, and j represents the fuel type correspondingly.

4.2.2 Statistical methods of CO2 emission for many ships

According to the computational methods of CO_2 emission for single ship, the computational methods of CO_2 emission for many ships are inferred:

$$\sum_{i=1}^{m}\sum_{k=1}^{N} EEOI_{ik} = \frac{\sum_{i=1}^{m}\sum_{k=1}^{N}\sum_{j=1}^{n} 44 Q_{ijk} * P_{jk} * r_{jk}}{\sum_{k=1}^{N}\sum_{i=1}^{m} 12\Delta_{ik} * D_{ik}} \tag{14}$$

$$= \frac{\sum_{i=1}^{m}\sum_{k=1}^{N}\sum_{j=1}^{n}\left\{44 P_{jk} * r_{jk} * \left[k_1 * \Delta^{\frac{2}{3}} * V^2 * D + \frac{D(k_2+F_A+F_B)}{V} + t_p(F_A+F_B)\right]_{ijk}\right\}}{\sum_{k=1}^{N}\sum_{i=1}^{m} 12\Delta_{ik} * D_{ik}}$$

In the formula (14), k represents the serial number of ship. It is convenient to calculate precisely CO2 emissions for a large number of vessels during a period of time by using formula (14).

The formula (13) can calculate the amount of ship CO2 emissions, provided that the ship is under the AIS signal coverage area. However, to count ship CO2 emissions in a certain region, it is necessary to extract eligible ships by comparing ship position with regional boundaries firstly, then using formula (14). Finally, it is available to obtain the overall ship CO_2 emissions within the region through summation of each ship CO_2 emissions; it is also accessible to assess the situation of CO_2 emissions from multiple perspectives according to different criteria, such as ship's tonnage, ship type and ship fleet.

4.3 Statistical processes of CO_2 emission

AIS information is divided into static information, dynamic information, voyage related information and security information. Due to traffic characteristics included in AIS information, monitoring ship traffic conditions in real-time through the analysis of AIS information comes true [10].

To gain accurate ship CO2 emission, estimated methods of CO2 emission, estimated methods of fuel consumption, computational methods of CO_2 emission for single ship and computational methods of CO_2 emission for many ships are listed. For assessing ship CO_2 emission totally in a certain region, Statistical flow chart of ship CO_2 emission is exhibited in Figure 5 [11-13]:

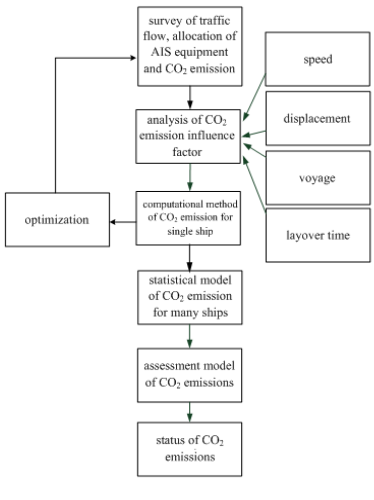

Figure 5: Statistical flow chart of ship CO2 emission

5. CONCLUSIONS

Currently, there is still no perfect ship CO2 emission monitoring system. The paper calculates the value of ship CO2 emissions during a period of time by analyzing AIS information and provides a new approach to monitor ship CO2 emission.

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