DESCRIPTION

Title of Invention

METHOD FOR SIMULATING FUEL CONSUMPTION USING HORSEPOWER INCREASE RATE OBTAINED IN CONSIDERATION OF FRICTIONAL RESISTANCE OF HULL, AND PROGRAM AND SYSTEM FOR EXECUTING THE SAME

Technical Field

[0001]

The present invention relates to a simulation method for estimating a fuel consumption (fuel efficiency) of a vessel, and more specifically, to a simulation method for estimating a fuel method of a vessel in consideration of a horsepower increase rate due to hull roughness and a horsepower increase rate due to hull fouling. The present invention also relates to a program and a system for executing the above-described simulation method.

Background Art

[0002]

It is necessary for a company/person that operates a vessel (vessel owner or operator) to accurately grasp a fuel consumption of the vessel and reduce the fuel consumption as much as possible (that is, improve propulsion performance)

not only from the viewpoint of cost reduction but also from the viewpoint of observing laws and regulations related to environmental problems. Manufacturers of paints for vessels are also required to research and develop paints and coating films capable of reducing a fuel consumption according to the operation status of vessels, and to select an optimal coating film at the time of building a vessel or at the time of periodic maintenance and to propose the same to the operating company/person. Therefore, there is a demand for a means capable of calculating a fuel consumption of a vessel as accurately as possible, estimating a change in a coating film applied to a hull and a change in the fuel consumption due to the change by simulation, and capable of being used by both the company/person that operates a vessel and the manufacturers of paints for vessels.

[0003]

The fuel consumption of a vessel is generally affected by magnitudes of resistance experienced by the hull during navigation, that is, wave-making resistance (resistance caused by energy lost due to waves generated by the hull), viscous pressure resistance (resistance caused when the hull is drawn backward by pressure difference due to vortexes generated backward by the hull), and frictional resistance (resistance due to friction generated between the

hull surface and surrounding water flows). As these resistances are larger, the horsepower required for the operation of the vessel is increased and thus the fuel consumption is also increased. In particular, since the frictional resistance accounts for 60 to 80% of the total resistance received by the hull, it is extremely important to reduce the frictional resistance in order to reduce the fuel consumption of the vessel.

[0004]

The frictional resistance is not constant, and fluctuates according to a change in the state of the hull surface accompanying operation. At the time of building a vessel or at the time of the initial period of docking a vessel (at the time of repairing a coating film), the hull roughness formed by a base treatment or coating process of the hull is mainly a factor of frictional resistance; however, when marine organisms adhere to the hull surface with operation and increase with time, such a fouling object is also added to the factor of frictional resistance, and the frictional resistance increases from the initial period. Meanwhile, the surface state of the coating film formed by the coating process also changes with time, and can be a factor that increases the frictional resistance as compared with the initial period (when the coating film becomes

rough) or a factor that decreases the frictional resistance (when the coating film becomes smooth). Therefore, it is important to estimate the change in frictional resistance and finally estimate the change in fuel consumption in consideration of such a change with time.

[0005]

Prior art documents disclosing matters related to the fuel consumption of a vessel or factors affecting the fuel consumption include, for example, the following.

[0006]

Patent Literature 1 describes a method for applying a coating to an external surface of a man-made object such as a vessel, the method including a computer-implemented "coating selection process" for selecting a coating having a minimum resistance rating in a set of coatings. The coating selection process includes a step of obtaining, for each coating included in the set, a "total roughness value of the external surface" based on a "fouling roughness value", a "macro roughness value", and a "micro roughness value" associated with each coating. The "fouling roughness value" is a roughness associated with the settlement of marine fouling organisms to the man-made object, and is said to be able to be calculated based on a dynamic fouling roughness value and an expected change in the fouling roughness value

with time, for example, by accessing a roughness database that associates a combination of each coating and a geographical region where the man-made object is expected to be located during the time period with a static fouling roughness value, retrieving the static fouling roughness value, and converting the static fouling roughness value to the dynamic fouling roughness value by accounting for an expected activity of the man-made object during the time period. The "macro roughness value" is a roughness originating from the surface of the man-made object, such as plate waviness, plate laps, weld seams, bolts, steel profile, corrosion of the man-made object, or damage to the man-made object, or a roughness originating from the substrate preparation and paint application process, and is said to be able to be calculated based on macro roughness score calculated based on at least one roughness score of a substrate macro roughness score, a coating macro roughness score, and a time-dependent macro roughness score. The "micro roughness value" is a roughness originating from the surface of the coating material, and is said to be able to be calculated based on a micro roughness score and a micro roughness score calculated based on a time-dependent micro roughness score. Patent Literature 1 also describes that a power requirement required to move a vessel at a desired

speed can be calculated for the hull coated with the selected coating, and the power requirement can be converted into a predicted fuel consumption or predicted greenhouse gas emission amount.

[0007]

As a technique related to roughness of a surface of an object related to frictional resistance, Patent Literature 2 describes a "three-dimensional surface roughness evaluating device", a "three-dimensional surface roughness evaluating method", a "three-dimensional surface roughness data acquiring device", and a "three-dimensional surface roughness data acquiring method" which are suitable for measurement of coating film roughness at the time of building or docking a vessel. Patent Literature 3 describes a "method of estimating a frictional resistance of a vessel bottom coating film" for estimating a frictional resistance increase rate (FIR) of the hull from parameters (R and RSm) related to the coating film roughness at the time of building or docking a vessel, and Patent Literature 4 describes a "method of predicting a frictional resistance" for estimating a frictional resistance increase rate (FIR) of the hull from the total exposed roughness projection area (A) per unit area exposed from the viscous sublayer thickness. Non Patent Literature 1 describes the importance

of including the influence of shape parameters including not only the "height" of the roughness (rough surface) of the object surface but also the "wavelength" or the like of the wavy rough surface when the frictional resistance is estimated.

[0008]

Non Patent Literature 2 describes how the roughness and frictional resistance of a hydrolyzable coating film and a silicone coating film used to prevent fouling of a hull change with time in water. Non Patent Literature 3 describes that the performance of the hull deteriorates with time due to biological adhesion or the like, leading to a speed loss and an increase in engine output for compensating for the speed loss, and shows a calculation formula, a graph, and the like as a rough indication. However, these two non patent literatures do not propose how to apply the described facts specifically to the simulation.

Citation List

Patent Literature

[0009]

Patent Literature 1: WO 2017/064016 (corresponding to JP 2019-502532 A and JP 7075339 B2)

Patent Literature 2: WO 2018/021210 (republication of

WO 2018/021210 A1)

Patent Literature 3: JP 2013-217766 A (corresponding to JP 5916490 B2)

Patent Literature 4: JP 2016-142719 A (corresponding to JP 6482888 B2)

Non Patent Literature

[0010]

Non Patent Literature 1: Hirohisa Mieno, PhD thesis, "Development of Frictional Resistance Increase Amount Estimation Method Based on Roughness Index of Hull Coating Film Surface", July 2020, Graduate School of Maritime Sciences, Kobe University

Non Patent Literature 2: Hisao Tanaka et al., "Influence of Surface Properties of Coatings to Frictional Resistance", Journal of the Kansai Society of Naval Architects, Japan, No. 239, March 2003

Non Patent Literature 3: MARINE ENVIRONMENT PROTECTION COMMITTEE, 63rd session, Agenda item 4, "AIR POLLUTION AND ENERGY EFFICIENCY A transparent and reliable hull and propeller performance standard Submitted by Clean Shipping Coalition (CSC)", 23 December 2011

Summary of Invention

Technical Problem

[0011]

Conventional simulation methods of a fuel consumption of a vessel, CII rating, and the like and systems for executing the simulation are insufficient to meet recent demands. For example, in the "step of obtaining the total roughness value of the external surface" included in the method described in Patent Literature 1, all roughness elements are summed up to obtain uniform roughness, and thus there is room for improvement in the accuracy of estimation of the fuel consumption of the vessel or the like. In addition, conventionally known technical matters are not necessarily well applied to simulation of the fuel consumption of a vessel.

[0012]

An object of the present invention is to provide a simulation method that is improved from a conventional method and can estimate a fuel consumption or the like of a vessel at an arbitrary time point and a change in fuel consumption or the like of the vessel in an arbitrary period. Another object of the present invention is to provide a program for causing a computer to execute the simulation method as described above, and a system for executing the simulation method as described above using a client terminal and a server connected to each other via a

network.

Solution to Problem

[0013]

The present inventors have found that the above problem can be solved by separately obtaining a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling, which are not distinguished in the conventional method for estimating the horsepower increase rate, summing these rates to obtain a total horsepower increase rate (PIR_a), and then estimating the fuel consumption and/or CII rating based on the total horsepower increase rate (PIR_a), thereby completing the present invention.

[0014]

That is, one aspect of the present invention includes at least the following configuration.

[Item 1]

A simulation method including a step of estimating a fuel consumption and/or CII rating of a vessel in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an arbitrary period, the simulation method including:

summing the separately determined PIR_r and PIR_f to obtain a total horsepower increase rate (PIR_a), and then finally estimating the fuel consumption and/or CII rating based on the total horsepower increase rate (PIR_a).

[Item 2]

The simulation method according to item 1, wherein the PIR_r is based on:

an initial horsepower increase rate (PIR_{r_0}) obtained from an initial frictional resistance increase rate (FIR_{r_0}) calculated based on a measured value or an estimated value of hull roughness, and

a time-dependent horsepower increase rate (PIR_{r_a}) obtained from a time-dependent frictional resistance increase rate (FIR_{r_a}) obtained by estimating and reflecting a change in hull roughness with time up to the arbitrary time point or within the arbitrary period.

[Item 3]

The simulation method according to item 1 or 2, wherein the PIR_f is

a time-dependent horsepower increase rate (PIR_{f_a}) obtained by estimating and reflecting hull fouling with time up to the arbitrary time point or within the arbitrary period.

[Item 4]

The simulation method according to any one of items 1 to 3, wherein the initial frictional resistance increase rate (FIR_{r_0}) and the time-dependent frictional resistance increase rate (FIR_{r_a}) due to hull roughness are calculated by Townsin's formula of ITTC 1978.

[Item 5]

The simulation method according to any one of items 1 to 4, wherein the initial frictional resistance increase rate (FIR_{r_0}) and the time-dependent frictional resistance increase rate (FIR_{r_a}) due to hull roughness are calculated based on

a projection area (A_r) of roughness exposed from a viscous sublayer thickness (δs_r) related to hull roughness.

[Item 6]

The simulation method according to item 5, wherein the exposed roughness projection area (A_r) related to hull roughness is calculated based on at least a height parameter (R) and a wavelength parameter (RSm) of the hull roughness.

[Item 7]

The simulation method according to item 6, wherein a size of a wall surface friction length (l_τ) used for calculating the viscous sublayer thickness (δs_r) related to hull roughness is changed by a correlation between a frictional resistance increase rate (FIR_{r_b}) obtained in a

frictional resistance range of at least two arbitrary frictional resistance tests and an exposed roughness projection area (A_r).

[Item 8]

The simulation method according to item 6, wherein the viscous sublayer thickness (δs_r) related to hull roughness is changed according to a frictional resistance value for each position.

[Item 9]

The simulation method according to any one of items 1 to 8, wherein the horsepower increase rate (PIR_f) due to hull fouling is calculated based on an average speed loss (AveSL) or an average horsepower increase rate (AvePIR).

[Item 10]

The simulation method according to item 9, wherein the average speed loss (AveSL) or average horsepower increase rate (AvePIR) is calculated according to a fouling risk (FR) of a route along which a vessel navigates.

[Item 11]

The simulation method according to any one of items 1 to 10, wherein the time-dependent horsepower increase rate (PIR_{f_a}) due to hull fouling is calculated by Townsin's formula of ITTC 1978 based on an estimated height of a fouling object shape and a fouling area.

[Item 12]

The simulation method according to any one of items 1 to 11, wherein the time-dependent horsepower increase rate (PIR_{f_a}) due to hull fouling is calculated based on

a time-dependent frictional resistance increase rate (FIR_{f_a}) calculated based on an exposure projection area (A_f) of an exposed fouling shape from an estimated height, a wavelength, and a viscous sublayer thickness (δs_f) related to a hull object.

[Item 13]

The simulation method according to item 12, wherein a size of a wall surface friction length (l_τ) used for calculating the viscous sublayer thickness (δs_f) related to the fouling object is changed by a correlation between a frictional resistance increase rate (FIR_{f_b}) obtained in a frictional resistance range of at least two arbitrary frictional resistance tests and an exposed roughness projection area (A_f).

[Item 14]

The simulation method according to any one of items 1 to 13, including a step of estimating a fuel consumption and/or CII rating in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at two or more arbitrary

time points or in an arbitrary period.

[Item 15]

The simulation method according to any one of items 1 to 14, including a step of estimating a fuel consumption and/or CII rating in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling for two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling.

[Item 16]

The simulation method according to any one of items 1 to 15, including a step of presenting a recommended one of two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling.

[Item 17]

A program for causing a computer to execute a simulation method of a fuel consumption and/or CII rating of a vessel in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an arbitrary period, the program including a configuration causing the computer to execute:

a process of summing the separately determined horsepower increase rate (PIR_r) due to hull roughness and

horsepower increase rate (PIR_f) due to hull fouling to obtain a total horsepower increase rate (PIR_a); and

a process of estimating the fuel consumption and/or CII rating based on the total horsepower increase rate (PIR_a).

[Item 18]

The program according to item 17, further including a configuration causing a computer to execute, in order to determine the horsepower increase rate (PIR_r) due to hull roughness:

a process of calculating an initial frictional resistance increase rate (FIR_{r_0}) based on a measured value or an estimated value of the hull roughness;

a process of obtaining an initial horsepower increase rate (PIR_{r_0}) from the initial frictional resistance increase rate (FIR_{r_0});

a process of calculating a time-dependent frictional resistance increase rate (FIR_{r_a}) obtained by estimating and reflecting a change in hull roughness with time up to the arbitrary time point or within the arbitrary period;

a process of obtaining a time-dependent horsepower increase rate (PIR_{r_a}) from the time-dependent frictional resistance increase rate (FIR_{r_a}); and

a process of determining the PIR_r from the initial

horsepower increase rate (PIR_{r_0}) and the time-dependent horsepower increase rate (PIR_{r_a}).

[Item 19]

The program according to item 17 or 18, further including a configuration causing a computer to execute, in order to determine the horsepower increase rate (PIR_f) due to hull fouling:

a process of calculating a time-dependent horsepower increase rate (PIR_{f_a}) obtained by estimating and reflecting hull fouling with time up to the arbitrary time point or within the arbitrary period to obtain the horsepower increase rate (PIR_f) due to hull fouling.

[Item 20]

The program according to any one of items 17 to 19, including a configuration capable of estimating a fuel consumption and/or CII rating in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at two or more arbitrary time points or in an arbitrary period.

[Item 21]

The program according to any one of items 17 to 20, including a configuration capable of estimating a fuel consumption and/or CII rating in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a

horsepower increase rate (PIR_f) due to hull fouling for two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling.

[Item 22]

The program according to any one of items 17 to 21, including a configuration capable of presenting a recommended one of two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling based on an estimated result of the fuel consumption and/or CII rating.

[Item 23]

A program for causing a client terminal connected to a server via a network to execute the program according to any one of items 17 to 22 in the server, the program including a configuration causing a computer to execute:

a process of transmitting data of a measured value or an estimated value of hull roughness from the client terminal to the server; and

a process of receiving data of a result calculated, obtained, determined, or estimated by the server and displaying the data on the client terminal.

[Item 24]

A computer-readable recording medium on which the program according to any one of items 17 to 22 is

continuously recorded.

[Item 25]

A computer-readable recording medium on which the program according to item 23 is continuously recorded.

[Item 26]

A system for executing, by using a client terminal and a server connected to each other via a network, simulation of a fuel consumption of a vessel in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an arbitrary period, wherein

the client terminal includes:

a means for transmitting at least data of a measured value or an estimated value of hull roughness to the server; and a means for receiving and displaying data of a result calculated, obtained, determined, or estimated by the server,

the server includes:

a process of summing the separately determined horsepower increase rate (PIR_r) due to hull roughness and horsepower increase rate (PIR_f) due to hull fouling to obtain a total horsepower increase rate (PIR_a); and

a means for estimating the fuel consumption and/or

CII rating based on the total horsepower increase rate (PIR_a), and

simulation is executed by the server in response to transmission of the data from the client terminal, and a result of the simulation is displayed on the client terminal.

[Item 27]

The system according to item 26, wherein the server further includes:

a means for calculating an initial frictional resistance increase rate (FIR_{r_0}) based on a measured value or an estimated value of the hull roughness received from the client terminal;

a means for obtaining an initial horsepower increase rate (PIR_{r_0}) from the initial frictional resistance increase rate (FIR_{r_0});

a means for calculating a time-dependent frictional resistance increase rate (FIR_{r_a}) obtained by estimating and reflecting a change in hull roughness with time up to the arbitrary time point or within the arbitrary period;

a means for obtaining a time-dependent horsepower increase rate (PIR_{r_a}) from the time-dependent frictional resistance increase rate (FIR_{r_a}); and

a means for determining a horsepower increase rate

(PIR_r) due to hull roughness from the initial horsepower increase rate (PIR_{r_0}) and the time-dependent horsepower increase rate (PIR_{r_a}).

[Item 28]

The system according to item 26 or 27, further including

a means for calculating a time-dependent horsepower increase rate (PIR_{f_a}) obtained by estimating and reflecting hull fouling with time up to the arbitrary time point or within the arbitrary period to obtain the horsepower increase rate (PIR_f) due to hull fouling.

[Item 29]

The system according to any one of items 26 to 28, wherein data specifying two or more arbitrary time points or an arbitrary period is transmitted from the client terminal to the server,

the server executes the simulation for two or more arbitrary time points or an arbitrary period in correspondence with the data, and

a result of the simulation is displayed on the client terminal.

[Item 30]

The system according to any one of items 26 to 29, wherein data specifying two or more hydrolyzable anti-

fouling paints or other conditions related to hull roughness or hull fouling is transmitted from the client terminal to the server,

the server executes the simulation for two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling in correspondence with the data, and

a result of the simulation is displayed on the client terminal.

[Item 31]

The system according to any one of items 26 to 30, wherein the server presents a recommended one of two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling based on an estimated result of the fuel consumption and/or CII rating, and

a simulation result including the recommendation is displayed on the client terminal.

[Item 32]

The system according to any one of items 26 to 31, wherein the server is operated by the computer-readable recording medium according to item 24.

[Item 33]

The system according to any one of claims 26 to 32, wherein the client terminal is operated by the computer-

readable recording medium according to item 25.

Advantageous Effects of Invention

[0015]

According to the simulation method of the present invention, it is possible to accurately determine a horsepower increase rate of a vessel as compared with the conventional case, estimate a fuel consumption and/or CII rating, and select a coating film more appropriate for the vessel. According to the program and system of the present invention, the company/person that operates a vessel, the manufacturers of paints for vessels, and the like can easily perform the simulation method of the present invention.

Brief Description of Drawings

[0016]

[Fig. 1] Fig. 1 shows an experimental result showing a reduction rate of a roughness height (parameter: average height Rc) of a hydrolyzable type paint.

[Fig. 2] Fig. 2 shows an experimental result showing a reduction rate of a roughness wavelength (parameter: average wavelength RSm) of the hydrolyzable type paint.

[Fig. 3] Fig. 3 illustrates an outline of steps of a simulation method and processes of a program in an

embodiment of the present invention.

[Fig. 4] Fig. 4 schematically illustrates a configuration of a system in an embodiment of the present invention.

[Fig. 5] Fig. 5 schematically illustrates an "FIR calculation form" in a client terminal in an embodiment of the present invention.

[Fig. 6] Fig. 6 schematically illustrates an "FIR (BSRA) calculation form" in the client terminal in an embodiment of the present invention.

[Fig. 7] Fig. 7 schematically illustrates a display screen of a calculation result of FIR_{r_0} in the client terminal in an embodiment of the present invention.

[Fig. 8] Fig. 8 schematically illustrates a "PIR calculation form" in the client terminal in an embodiment of the present invention.

[Fig. 9-1] Fig. 9-1 schematically illustrates simulation results (first half) of FOC and CII rating in the client terminal in an embodiment of the present invention.

[Fig. 9-2] Fig. 9-2 schematically illustrates simulation results (second half, continuation of Fig. 9-1) of FOC and CII rating in the client terminal in an embodiment of the present invention.

Description of Embodiments

[0017]

Hereinafter, unless otherwise indicated, the "invention described in the present specification" is referred to as the "present invention". For example, the "simulation method described in the present specification" is referred to as the "simulation method of the present invention". That is, the "present invention" is not limited to the inventions of the aspects listed in "Solution to Problem" in the present specification corresponding to the CLAIMS, but the present invention generally refers to the inventions described in Summary of Invention and Description of Embodiments in the present specification.

[0018]

-Simulation method-

A simulation method of the present invention is a simulation method including a step of estimating a fuel consumption and/or CII rating of a vessel in consideration of a horsepower increase rate (referred to as "PIR_r" in the present specification) due to hull roughness and a horsepower increase rate (referred to as "PIR_f" in the present specification) due to hull fouling at an arbitrary time point or in an arbitrary period, the simulation method including:

summing the separately determined PIR_r and PIR_f to obtain a total horsepower increase rate (referred to as "PIR_a" in the present specification), and then finally estimating the fuel consumption and/or CII rating based on the total horsepower increase rate (PIR_a).

[0019]

The PIR_r in the present invention is typically based on: an initial horsepower increase rate (referred to as "PIR_{r_0}" in the present specification) obtained from an initial frictional resistance increase rate (referred to as "FIR_{r_0}" in the present specification) calculated based on a measured value or an estimated value of hull roughness, and a time-dependent horsepower increase rate (referred to as "PIR_{r_a}" in the present specification) obtained from a time-dependent frictional resistance increase rate (referred to as "FIR_{r_a}" in the present specification) obtained by estimating and reflecting a change in hull roughness with time up to the arbitrary time point or within the arbitrary period. However, it is also possible to treat, as the PIR_r in the present invention, the horsepower increase rate due to hull roughness according to a definition different (modified) from the above typical example.

[0020]

The PIR_f in the present invention is typically a

time-dependent horsepower increase rate (referred to as "PIR_{f_a}" in the present specification) obtained by estimating and reflecting hull fouling with time up to the arbitrary time point or within the arbitrary period. Note that, since there is no hull fouling at the time of building a vessel or at the time of docking a vessel (after repairing, before launching), there is no initial horsepower increase rate in which hull fouling at the time of building or docking a vessel is estimated and reflected in the above definition. However, it is also possible to treat, as the PIR_f in the present invention, the horsepower increase rate due to hull fouling according to a definition different (modified) from the above typical example.

[0021]

·FIR

The "FIR" (Friction Increase Ratio: frictional resistance increase rate) in the present invention, typically FIR_{r_0}, FIR_{r_a}, FIR_{f_a}, or the like described above is an increase rate (%) of frictional resistance with reference to a mirror surface, and is a commonly known technical term for those skilled in the art.

[0022]

The FIR is typically a numerical value obtained by the following first calculation method and second

calculation method or other calculation methods. In the present invention, the FIR calculated based on a "measured value" or "estimated value" (and other necessary numerical values) of "hull roughness" acquired for the hull at the time of building a vessel or at the time of docking a vessel (after repairing, before launching) can be set as the initial frictional resistance increase rate "FIR_{r_0}". The FIR obtained by estimating and reflecting a change in "hull roughness" with time up to the arbitrary time point or within the arbitrary period can be set as "FIR_{r_a}", and the FIR obtained by estimating and reflecting a change in "fouling object" with time can be set as "FIR_{f_a}".

[0023]

·Roughness

The roughness of the hull, the evaluation device, and the like can be acquired by "measurement" or "estimation" by a general method in the present technical field or a known method. For example, the roughness can be measured using a contact or non-contact automatic or manual surface roughness measurement device.

[0024]

Examples of a first embodiment of the measured value of the roughness include a measured value (also referred to as "BSRA roughness" in the present specification) acquired

using a stylus-type displacement meter (BSRA-type roughness meter) developed by the British Ship Building Association (BSRA) (see D. Byrne (1983), Hull roughness and the impact of outer hull maintenance decisions on ship efficiency, The First International Shiprepair, Spares and Maintenance Conference, p33-51). In the case of using a BSRA-type roughness meter, difference (Pt_{50}) between a maximum peak and a maximum valley in an evaluation length of 50 mm is obtained as a measured value (BSRA roughness).

[0025]

Examples of a second embodiment of the measured value of the roughness include a measurement value (referred to as "three-dimensional roughness" in the present specification) acquired using a non-contact type laser displacement meter. In the second embodiment, it is preferable to use the "three-dimensional surface roughness evaluating device", the "three-dimensional surface roughness evaluating method", the "three-dimensional surface roughness data acquiring device", and the "three-dimensional surface roughness data acquiring method" described in the aforementioned Patent Literature 2 (WO 2018/021210) which are suitable for measurement of coating film roughness at the time of building or docking a vessel and can rapidly, continuously, in large quantities, and directly acquire the surface roughness parameter related

to the three-dimensional surface roughness of an object, a structure, or the like that cannot be transported. By performing measurement according to the provision of JIS B 0601:2001 (ISO 4287:1997) using a non-contact type laser displacement meter, Rz (maximum height roughness: sum of maximum peak height and maximum valley depth of roughness curve in reference length), Rc (average height of roughness curve element), Ra (arithmetic average roughness), Rq (root mean square roughness), RZJIS (ten-point average roughness: the sum of the average of the peak heights from the highest peak to the fifth peak in descending order and the average of the valley depths from the deepest valley to the fifth peak in descending order), and the like can be acquired as the height parameter R. When the second embodiment is used as the measured value of the hull roughness in the present invention, reference can be made to Patent Literature 2 for details (terms and symbols in formulae shall be read as appropriate to the present invention) if necessary.

[0026]

The initial “estimated value” of the hull roughness can be estimated by observing the roughness parameter (height) and the wavelength when the paint specification is changed for each paint product. The “estimated value” of the temporal change of the hull roughness can be estimated

by observing the temporal change of the roughness parameter (height) and the wavelength due to the exposure to the water flow in which the temperature and the velocity are changed in advance for each paint product.

[0027]

·First calculation method of FIR

Examples of the first calculation method for calculating the frictional resistance increase rate (FIR) based on a measured value or an estimated value of the roughness include a method in which ΔC_F (a frictional resistance coefficient related to a Reynolds number for a measured water temperature value and a measured salt concentration value) is calculated by the following Townsin's formula (the following Formula 1) of ITTC 1978 and a value calculated by the following Formula 3 is regarded as FIR (see ITTC Quality System Manual Recommended Procedures and Guidelines, Preparation, Conduct and Analysis of Speed/Power Trials, Effective Date 2017, Revision 07).

[0028]

[Math. 1]

$$\Delta C_F = 0.044\left[\left(\frac{k_s}{L_{WL}}\right)^{\frac{1}{3}} - 10Re^{-\frac{1}{3}}\right] + 0.000125 \quad \text{(Formula 1)}$$

In Formula 1, k_s is an average value of heights of

"hull roughness" (average roughness height), L_{wL} is a vessel length at a waterline (L_{pp}: it can also be regarded as a vessel length), and Re is a Reynolds number calculated by the following Formula 2. For k_s used here, the difference (Pt_{50}) between a maximum peak and a maximum valley in an evaluation length of 50 mm is generally the same as the measured value (BSRA roughness).

[0029]

[Math. 2]

$$Re = \rho v l / \mu = v l / \nu \qquad \text{(Formula 2)}$$

In Formula 2, ρ is a density [kg/m^3] of the fluid, v is a representative flow velocity [m/s], l is a representative length [m], μ is a viscosity coefficient [Pa·s, kg/(m·s)] of the fluid, and ν (= ρ/μ) is a kinematic viscosity coefficient [m^2/s]. l corresponds to L_{wL} (L_{pp}) in Formula 1 and can be the same value.

[0030]

[Math. 3]

$$FIR\ (\%) = \Delta C_F / C_{F0} \qquad \text{(Formula 3)}$$

In Formula 3, C_{F0} is a frictional resistance coefficient for a water temperature reference value and a salt concentration reference value.

[0031]

k_s is a measured value using a BSRA roughness meter (BSRA HULL ROUGHNESS ANALYZER) in the related art, but can also be a measured value using a means for actually measuring the height parameter (R) of hull roughness used in the "second calculation method of FIR" described below, for example, a three-dimensional roughness meter.

[0032]

·Second calculation method of FIR

Examples of the second calculation method for calculating the frictional resistance increase rate (FIR) based on a measured value or an estimated value of roughness include a method of calculating the frictional resistance increase rate based on the projection area (A_r) of exposed roughness from a viscous sublayer thickness (δs_r) related to the hull roughness.

[0033]

Examples of the calculation formula for determining A_r by the second method include the following Formula 4 described in the aforementioned Patent Literature 4 (JP 2016-142719 A) and Non Patent Literature 1 (conical model). In the case of using the second method in the present invention, reference can be made to the patent literature and the non patent literature for details (terms and symbols

in formulae shall be read as appropriate to the present invention) if necessary.

[0034]

[Math. 4]

$$FIR_{(\%)} = C \times A_r \qquad \text{(Formula 4)}$$

In Formula 4, A_r is a total exposed roughness projection area (referred to as "exposed projection area of hull roughness" in the present specification) per unit area exposed from the viscous sublayer thickness (referred to as "δs_r" in the present specification) related to the hull roughness, and C is a coefficient dependent on A_r.

[0035]

·C

C can be calculated from the relationship between the following two formulas with reference to the aforementioned Patent Literature 3 (JP 2013-217766 A). That is, the FIR is determined from the measured value acquired by the frictional resistance test using the double cylindrical device by the following Formula 7, and then C can be determined from the FIR, R, and RSm by the following Formula 5.

[0036]

[Math. 5]

$$FIR_{(\%)} = C \times R^2 / RSm \qquad \text{(Formula 5)}$$

In Formula 5, R is a roughness height parameter, RSm is a roughness wavelength parameter, and C is a coefficient that depends on a type of R (roughness height parameter) and a frictional resistance test method.

[0037]

R and RSm used in Formula 5 can be obtained in advance for a plurality of hull coating films having different roughnesses (the same as those used in the following Formula 7) with a constant evaluation length (for example, the evaluation length is 10,000 μm or more and the measurement interval is 500 μm or less) by the above-described method (for example, the second embodiment using a laser displacement meter). R is, for example, any of Rz, Rc, Ra, Rq, and RZJIS acquired according to the provision of JIS B 0601:2001 (ISO 4287:1997). RSm is a value obtained by the following Formula 6.

[0038]

[Math. 6]

$$RSm = \frac{1}{m}\sum_{i=1}^{m} Xsi \qquad \text{(Formula 6)}$$

In Formula 6, Xs is a length of each roughness curve

element, and RSm is calculated as an average of the lengths Xs of the roughness curve elements.

[0039]

[Math. 7]

$$FIR_{(\%)} = (\tau - \tau_0) / \tau_0 \times 100 \qquad \text{(Formula 7)}$$

In Formula 7, τ_0 and τ are respectively a shear stress (τ_0) calculated from a test body having a smooth surface and a shear stress (τ) calculated from a roughness test body formed by applying the hull paint (forming the hull coating film) in the frictional resistance test. For example, the shear stress (τ) can be calculated from the shear stress (τ_0) calculated from the torque acting on the inner cylinder of the mirror surface when the outer cylinder is rotated under the same conditions and the torque acting on the roughness inner cylinder formed by applying the hull paint (forming the hull coating film) in the frictional resistance test using the double cylindrical device.

[0040]

·A_r

A_r is preferably calculated according to the provision of JIS B 0601:2001 (ISO 4287:1997) based on the height parameter R related to the hull roughness and the average length RSm of the roughness curve element as the

roughness wavelength λ.

[0041]

For example, when Rc (average height of roughness curve elements) is used as the height parameter R of the hull roughness, A_r can be calculated by the following Formula 8. Note that δs_r in Formula 8 is the viscous sublayer thickness related to the hull roughness, similarly to δs_r related to A_r in Formula 4.

[0042]

[Math. 8]

$$A_r = 0.5 \times (Rc - \delta s_r)^2 / (Rc \times RSm) \qquad \text{(Formula 8)}$$

[0043]

δs_r can be calculated by the following Formula 9 using a frictional resistance test of a smooth surface.

[0044]

[Math. 9]

$$u^* = (\tau_0 / \rho)^{1/2} \qquad \text{(Formula 9)}$$

In Formula 9, u^* is the friction velocity (m/s), τ_0 is the smooth surface shear stress (N/m^2), and ρ is the density (kg/m^3). ρ in Formula 9 corresponds to ρ in Formula 2 related to Re (Reynolds number). τ_0 in Formula 9 corresponds to τ_0 in Formula 7.

[0045]

[Math. 10]

$$l_\tau = \nu / u^* \qquad \text{(Formula 10)}$$

In Formula 10, l_τ is a wall surface friction length (m), and ν is a kinematic viscosity coefficient (m^2/s).

[0046]

[Math. 11]

$$\delta s_r = l_\tau \times y^+ \qquad \text{(Formula 11)}$$

In Formula 11, y^+ is a dimensionless distance.

[0047]

When Ra (arithmetic average roughness) is used as the height parameter R of the hull roughness, A_r can be calculated by the following Formula 12.

[0048]

[Math. 12]

$$A_r = (Ra - \delta s_r) / RS_m \qquad \text{(Formula 12)}$$

[0049]

In Formula 12, the size of l_τ used for calculating δs_r is preferably changed by the correlation between the frictional resistance increase rate (FIR_{r_b}) obtained in the frictional resistance range of at least two arbitrary

frictional resistance tests and the exposed roughness projection area (A_r).

[0050]

In the above formula, δs_r is preferably changed according to the frictional resistance value for each position of the hull.

[0051]

In the present invention, it is possible to more accurately calculate the FIR of the entire hull by specifying R (height parameter of hull roughness), RSm (average length of roughness curve element), δs_r, and other necessary values for each position of the hull, calculating the FIR for each position of the hull, and then integrating the FIR with the hull length.

[0052]

Simply, for example, the hull is divided into a flat bottom part (also referred to as “FB” in the present specification), a vertical bottom part (also referred to as “VB” in the present specification), and a boot top part (also referred to as “BT” in the present specification), and the FIR of the entire hull can be determined as follows.

[0053]

For example, when the frictional resistance coefficient is assigned to each position of the hull as C_{F_FB}

$= 0.6 \times C_{F_VB}$, δs_r calculated from the shear stress τ_0 of the smooth surface for each place changes, and the FIR calculated for each place changes. Here, a technique of accurately calculating the shear stress τ_0 for each location using CFD (numerical fluid simulation or the like) is also included.

[0054]

As a method other than the first measurement method and the second measurement method for calculating the frictional resistance increase rate (FIR) based on a measured value or an estimated value of roughness, for example, it is also possible to use Formula 2 described in the aforementioned Patent Literature 3 (JP 2013-217766 A), which is used to determine C in the second measurement method.

[0055]

·FIR_{r_0}

The initial frictional resistance increase rate (FIR_{r_0}) related to the hull roughness can be calculated by using the "hull roughness" acquired by various means at the time of building or docking a vessel as the "roughness" in each formula in the first calculation method, the second calculation method, or another calculation method of FIR as described above.

[0056]

·FIR_{r_a}

The initial frictional resistance increase rate (FIR_{r_0}) related to the hull roughness can also be calculated by using the "hull roughness" measured by various means after a certain period of time elapses as the "roughness" in each formula in the first calculation method, the second calculation method, or another calculation method of FIR as described above.

[0057]

However, in the present invention, the time-dependent frictional resistance increase rate (FIR_{r_a}) related to the hull roughness is preferably estimated by using reference data prepared for various hull coating films and indicating the relationship between the elapsed time and the height parameter (R) and the wavelength parameter (RSm) of the hull roughness.

[0058]

The reference data can be created, for example, as follows. A test plate on which various hull coating films are formed is immersed in water (typically in seawater), and the height parameter (R) and the wavelength parameter (RSm) of the hull roughness are periodically (for example, every month) measured. After a sufficient number of measured

values are obtained, a scatter diagram in which the elapsed time is taken on the horizontal axis and the reduction rates of R and RSm are taken on the vertical axis is created, and an approximate curve by the least squares method is determined. Note that the "reduction rate" can be either a positive numerical value or a negative numerical value, and the negative reduction rate can also be referred to as an increase rate. By extrapolating an arbitrary elapsed period to the approximate curve thus obtained, an estimated value of the reduction rate of R or RSm after the elapsed period is obtained. By multiplying the initial values of R and RSm by the estimated values of their reduction rates, estimated values of R and RSm after an arbitrary elapsed period are determined. By using the estimated value as R and RSm in each of the above formulas, an estimated value after an arbitrary elapsed period of the FIR, that is, an estimated value of the time-dependent frictional resistance increase rate (FIR_{r_a}) is determined.

[0059]

The behavior of change with time in the height parameter (R) and the wavelength parameter (RSm) of the hull roughness varies depending on the type of coating film. Since hydrolyzable type coating films generally have a smooth surface with time, R, for example, Rc (average height

of roughness curve elements), decreases with time and RSm increases with time, in other words, the reduction rate of R increases with a positive value with time (see Fig. 1), while the reduction rate of RSm decreases with a negative value with time (see Fig. 2). On the other hand, since a disintegration-type coating film generally has a rough surface with time, R increases with time, and RSm also decreases with time, in other words, the reduction rate of R decreases with time by a negative value, but the increase rate of RSm also increases with time by a negative value. Since the surface of a silicone-type coating film hardly changes with time, both R and RSm hardly change with time, in other words, both the reduction rate and the increase rate of R and RSm are almost zero.

[0060]

·FIR_{f_a}

The time-dependent frictional resistance increase rate (FIR_{f_a}) related to hull fouling can be determined by assigning a roughness shape to biological fouling, deriving a necessary parameter, and then calculating the frictional resistance increase rate (FIR) related to hull roughness by the first calculation method (a method of calculating by Townsin's formula of ITTC 1978 using k_s or the like) or the second calculation method (a method of calculating by the

formula described in JP 2013-217766 A (Patent Literature 3) using R, RSm, and the like) as described above. The parameter when the roughness shape is assigned to the biological fouling after a certain period of time elapses for determining FIR_{f_a} can be estimated by using reference data prepared for various hull coating films and indicating the relationship between the elapsed time and the height parameter (R) and the wavelength parameter (RSm) indicating the density of the possible fouling shape, similarly to the parameter for obtaining the time-dependent frictional resistance increase rate (FIR_{r_a}) related to the hull roughness as described above.

[0061]

·PIR

The "PIR" (Power Increase Ratio: horsepower increase rate) in the present invention is an increase rate (%) of the horsepower with reference to the mirror surface, and is a well-known technical term for those skilled in the art. The present invention estimates the fuel consumption and/or CII rating of a vessel in consideration of the horsepower increase rate (PIR_r) due to hull roughness and the horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an arbitrary period as the horsepower increase rate (PIR), and after separately

determining the PIR_r and the PIR_f, the PIR_r and the PIR_f are summed up to obtain the total horsepower increase rate (PIR_a) as shown in the following Formula 13.

[0062]

[Math. 13]

$$PIR_a = PIR_r + PIR_f \quad \text{(Formula 13)}$$

[0063]

·PIR_r

The total horsepower increase rate (PIR_r) related to hull fouling is a value obtained by the initial horsepower increase rate (PIR_{r_0}) related to the hull roughness at the time of building a vessel or at the time of docking a vessel (after repairing of the coating film, before launching) and the time-dependent horsepower increase rate (PIR_{r_a}) related to the hull roughness after a certain period of time elapses (after launching). PIR_{r_0} is typically obtained from the initial frictional resistance increase rate (FIR_{r_0}) determined by the calculation method described in the present specification, and PIR_{r_a} is obtained from the time-dependent frictional resistance increase rate (FIR_{r_a}) determined by the method described in the present specification.

[0064]

·Calculation method of PIR_{r_0} and PIR_{r_a}

PIR_{r_0} and PIR_{r_a} can be calculated by multiplying FIR_{r_0} and FIR_{r_a} by Form Factor (a coefficient indicating the ratio of the frictional resistance in the total resistance), that is, by the following Formulas 14 and 15, respectively. Form Factor is, for example, 0.7, and at this time, PIR_{r_0} is expressed as $FIR_{r_0} \times 0.7$ and PIR_{r_a} is expressed as $FIR_{r_a} \times 0.7$.

[0065]

[Math. 14]

$$PIR_{r_0} = FIR_{r_0} \times \text{Form Factor} \quad \text{(Formula 14)}$$

[Math. 15]

$$PIR_{r_a} = FIR_{r_a} \times \text{Form Factor} \quad \text{(Formula 15)}$$

[0066]

Form Factor is a value defined by the following Formula 16.

[Math. 16]

$$\text{Form Factor} = C_f / C_t \quad \text{(Formula 16)}$$

In Formula 16, C_t is the total resistance coefficient including the wave-making resistance, the viscous pressure resistance, and the frictional resistance, and C_f is the

frictional resistance coefficient.

[0067]

·PIR_f

As the total horsepower increase rate (PIR_f) related to hull fouling, the time-dependent horsepower increase rate (PIR_{f_a}) obtained by estimating and reflecting the hull fouling with time up to an arbitrary time point or within an arbitrary period after a certain period of time elapses (after launching) from the time of building of a vessel or the time of docking of a vessel can be directly applied.

[0068]

·First calculation method of PIR_f

The first calculation method of PIR_f is a method of calculating PIR_f based on the "average speed loss" (referred to as "AveSL" in the present specification) or the "average horsepower increase rate" (referred to as "AvePIR" in the present specification), and the following Formula 17 and the following Formula 18 are used, respectively. AveSL and AvePIR are both measurement items over the service life, specifically 5 years (60 months, see the aforementioned Non Patent Literature 3) of an anti-fouling coating film standardized by ISO19030, and generally have a relationship of the following Formula 19.

[0069]

[Math. 17]

$$\mathrm{AveSL} = \mathrm{SL}_{_1e} - \mathrm{SL}_{_1b} \quad \text{(Formula 17)}$$

In Formula 17, $SL_{_1e}$ is an average value of speed loss in the subsequent 4 years (evaluation period), and $SL_{_1b}$ is an average value of speed loss in the first 1 year (benchmark period).

[Math. 18]

$$\mathrm{AvePIR} = \mathrm{PIR}_{_1e} - \mathrm{PIR}_{_1b} \quad \text{(Formula 18)}$$

In Formula 18, $PIR_{_1e}$ is an average value of PIR for the subsequent 4 years (evaluation period), and $PIR_{_1b}$ is an average value of PIR for the first 1 year (benchmark period). $PIR_{_1e}$ and $PIR_{_1b}$ may be numerical values obtained in the same manner as PIR_a, or may be numerical values determined by other known methods.

[0070]

[Math. 19]

$$3 \times \mathrm{AveSL} = \mathrm{AvePIR} \quad \text{(Formula 19)}$$

[0071]

In the first calculation method of PIR_f, the average speed loss (AveSL) and the average horsepower increase rate (AvePIR) are preferably calculated according to the fouling

risk (FR) of the route along which a vessel navigates.

[0072]

Calculating AveSL and AvePIR depending on the "performance of the anti-fouling paint composition applied to the hull" refers to obtaining data of AveSL and AvePIR under referable conditions (for example, after conditions other than the performance of the anti-fouling paint composition, such as the route or the fouling risk (FR) thereof, the base treatment, and others, are made uniform, or the variation is suppressed within an allowable range, or even when there is a certain variation in those conditions, the variation can be appropriately processed as big data and referred to) for various anti-fouling paint compositions having different performances that may be applied to the hull, extracting data of AveSL and AvePIR (suitable for use as a reference) corresponding to the anti-fouling paint composition to be simulated therefrom, and calculating AveSL and AvePIR.

[0073]

Calculating AveSL and AvePIR according to the "fouling risk (FR) of the route along which a vessel navigates" means acquiring data of AveSL and AvePIR under referable conditions (for example, after the anti-fouling paint composition, the base treatment, and conditions other

than the fouling risk (FR) are made uniform, or kept within an allowable range, or even when there is a certain degree of variation in these conditions, the data can be appropriately processed as big data and referred to) for various routes (sea areas) with different fouling risks, along which the hull may navigate, extracting data of AveSL and AvePIR corresponding to the route to be simulated (suitable to be used as a reference) from the data, and calculating AveSL and AvePIR preferably after improving accuracy based on a correlation analysis with the fouling risk (FR).

[0074]

Examples of a first setting element of the fouling risk (FR) include: a measurement value (r), which is a continuous numerical value and can be measured in real time at a predetermined measurement interval (for example, every predetermined number of hours) during the voyage of a vessel, such as the seawater temperature, the chlorophyll amount, and the like of the route along which the vessel navigates; and an environmental indicator value (EP) based on the sum of products of a measurement interval (t) of the measurement value (r). The measurement interval (a) may be fixed or varied, and in a generalized manner, the environmental indicator value (EP) can be expressed by the

following Formula 20.

[0075]

[Math. 20]

$$\text{Environmental indicator value EP} = \sum_{i=1}^{n} r_i t_i \qquad \text{(Formula 20)}$$

(r_i: Fouling risk of region i, t_i: Staying time in region i)

[0076]

Examples of a second setting element of the fouling risk (FR) include operation indicator values (NP) such as a ship speed and an operation rate. The fouling risk (FR) can be calculated at least by a combination of the environmental indicator value (EP) and the operation indicator value (NP), but an anti-fouling paint composition, base treatment, and other data can be additionally used.

[0077]

Meanwhile, the accuracy of AveSL and AvePIR to be calculated can be improved by performing correlation analysis and processing by multivariate analysis or AI analysis on the relationship between the fouling record in the past operation and the reference AveSL and reference AvePIR using the environmental indicator value (EP) and the operation indicator value (NP) at the time of the operation, and if necessary, additionally using the anti-fouling paint composition and the base treatment, and other data.

[0078]

It is one of preferred embodiments of the first calculation method of PIR_f to further improve the accuracy as described above based on the fouling risk (FR) obtained as described above and then present PIR_f corresponding to the patterns of the routes and the anchoring positions of various vessels.

[0079]

·Second calculation method of PIR_f

The second calculation method of PIR_f, that is, PIR_{f_a}, is a method of performing calculation based on Townsin's formula of ITTC 1978, similarly to Formula 1 described in relation to the first calculation method of FIR. Here, k_s is defined as an average value (average roughness height) of the height of the "hull roughness" in the description of Formula 1, but ΔC_F for the "hull fouling" can be calculated by replacing k_s with the "estimated average height of the fouling object shape". Furthermore, the time-dependent friction increase rate FIR_{f_a} due to "hull fouling" can be obtained by using Formula 3. Finally, in Formula 15, the time-dependent horsepower increase rate PIR_{f_a} due to "hull fouling" is determined by using the time-dependent friction increase rate FIR_{f_a} due to "hull fouling" instead of the time-dependent friction increase rate FIR_{r_a}

due to "hull roughness", and the time-dependent horsepower increase rate can be set as PIR_f.

[0080]

·Third calculation method of PIR_f

The third calculation method of PIR_f, that is, PIR_{f_a}, is a method of calculating PIR_f based on FIR_{f_a} obtained by applying formulas described in the aforementioned Patent Literature 4 (JP 2016-142719 A) and Non Patent Literature 1 (conical model), similarly to Formulas 3 to 12 described in relation to the second calculation method of FIR. Here, in Formula 4, A_r defined as the total exposed roughness projection area per unit area exposed from the viscous sublayer thickness (δs_r) related to "hull roughness" (exposed projection area of hull roughness), and C defined as the coefficient dependent on A_r are used; however, by using A_f defined as the total exposed roughness projection area per unit area exposed from the viscous sublayer thickness (referred to as "δs_f" in the present specification) related to "hull fouling" (exposed projection area of hull fouling), and C_f defined as the coefficient dependent on A_f, respectively, the time-dependent friction increase rate FIR_{f_a} due to "hull fouling" can be determined. C_f can be calculated by using, in Formula 5, the estimated height of the "fouling object" as R, the roughness

wavelength parameter Rs_f indicating the density of the "fouling object" calculated in the same manner as in Formula 6 as RSm, and the FIR measured by the frictional resistance test for the "fouling object" calculated in the same manner as in Formula 7 as the FIR. In Formulas 8 to 11, A_f can be calculated by using each numerical value such as a parameter related to "hull fouling" or "fouling object" instead of each numerical value such as a parameter related to "hull roughness".

[0081]

In the third calculation method of PIR_f described above, the size of l_τ used for calculating δs_f in the same manner as in Formula 11 is also preferably changed by the correlation between the frictional resistance increase rate (FIR_{f_b}) obtained in the frictional resistance range of at least two arbitrary frictional resistance tests and the exposed roughness projection area (A_f).

[0082]

In the third calculation method of PIR_f, it is preferable to calculate PIR_f by the following Formula 21 in consideration of the fouling area (%) and the Form Factor together with FIR_{f_a}. Note that PIR_{f_a} calculated by such a third calculation method may be referred to as PIR_{f_s} in the present specification.

[0083]

[Math. 21]

$$PIR_{f_a} = FIR_{f_a} \times \text{Fouling area(\%)} \times \text{Form Factor} \quad \text{(Formula 21)}$$

The fouling area (%) can be estimated by using "reference data" (which can be said to be in accordance with the reference data described above in relation to FIR_{f_a}) indicating the relationship between the elapsed time and the fouling area in the hull prepared for various hull coating films. As the Form Factor, a value similar to Form Factor in Formula 16 can be used.

[0084]

Alternatively, for example, it is more preferable to divide the hull into a flat bottom part (FB), a vertical bottom part (VB), and a boot top part (BT), and determine PIR_{f_a} for the entire hull in consideration of the fouling area of each part.

[0085]

·PIR_a

By the means as described in the present specification, the total horsepower increase rate (PIR_a) can be determined by calculating PIR_r and PIR_f and summing them. Further subsequently, a fuel consumption (also referred to as "FOC" in the present specification) and/or CII rating may

ultimately be estimated based on the PIR_a.

[0086]

·FOC

The fuel consumption (FOC, MT/year) can be calculated, for example, by the following Formula 22 using the total horsepower increase rate (PIR_a) obtained for the current state of the hull and the reference FOC estimated (calculable by calculation) when the total horsepower increase rate is 0 as the reference fuel consumption (FOC_r) not affected by the PIR occurring in each coating specification.

[0087]

[Math. 22]

$$yFOC = FOC_r \times PIR_a \qquad \text{(Formula 22)}$$

[0088]

The annual fuel consumption (yFOC, MT/year) can be calculated from the fuel consumption (dFOC, MT/day) per day and the number of operating days (for example, 237 day/year) by the following Formula 23. Note that the initial value of yFOC is set as “iFOC” (initial FOC).

[0089]

[Math. 23]

$$yFOC = dFOC \times \text{Number of operating days} \quad \text{(Formula 23)}$$

[0090]

According to the following Formula 24, the monthly fuel consumption (mFOC, MT/year) can be calculated based on the iFOC. Note that yFOC is equal to the sum of mFOCs for all 12 months in each year.

[0091]

[Math. 24]

$$mFOC = iFOC/12 \times \{1 + (\text{Number of elapsed months}/60) \times \text{AvePIR} \times 2\} \quad \text{(Formula 24)}$$

[0092]

According to the following Formula 25, the annual CO_2 emission amount (yCO_2) can be calculated based on yFOC.

[0093]

[Math. 25]

$$yCO_2 = yFOC \times (t\text{-}CO_2 / t\text{-}Fuel) \quad \text{(Formula 25)}$$

In Formula 25, ($t\text{-}CO_2$/t-Fuel) is a value defined by the International Maritime Organization (IMO) for each fuel type.

[0094]

The actual value of CII (Attained CII: ${}_{A}CII$) can be

calculated based on yCO_2 by the following Formula 26.

[0095]

[Math. 26]

$$_{A}CII = yCO_2 / (DWT \text{ or } GT \times \text{Nautical distance}) \quad \text{(Formula 26)}$$

In Formula 26, DWT is dead weight tonnage and GT is gross tonnage. DWT is used when the vessel type is a bulk-carrier, a tanker, a container ship, a gas ship (LPG/CNG), an LNG ship, a general cargo ship, a refrigerated cargo ship, or a combination carrier, and GT is used when the vessel type is a cruise ship, an automobile cargo ship, a RoRo cargo ship, or a RO-PAX ferry.

[0096]

The annual evaluation reference value (Required CII: $_{R}CII$) of CII can be calculated based on the CII average value (CII_{ref}) for each vessel type in 2019 by the following Formula 27. CII_{ref} can be calculated by the following Formula 28.

[0097]

[Math. 27]

$$_{R}CII = CII_{ref} \times (100\text{-}z) / 100 \quad \text{(Formula 27)}$$

In Formula 27, z represents a reduction rate from 2019, and is a value added by 2% every year from 2023 (z =

5%).

[0098]

[Math. 28]

$$CII_{ref} = a \times DWT^{-c} \quad \text{(Formula 28)}$$

In Formula 28, a and c are numerical values determined in advance for each vessel type (see IMO, MARINE ENVIRONMENT PROTECTION COMMITTEE 79th session Agenda item 7). Note that the DWT in the above formula may be GT or a constant depending on the vessel type.

[0099]

The evaluation value (d) of CII can be calculated based on ${}_{A}CII$ and ${}_{R}CII$ by the following Formula 29.

[0100]

[Math. 29]

$$d = {}_{A}CII \,/\, {}_{R}CII \quad \text{(Formula 29)}$$

[0101]

The CII rating is determined based on which range, which is formed by the threshold value (d1, d2, d3, and d4) predetermined for each vessel type and the ${}_{R}CII$, the evaluation value (d) of CII belongs to. Rating is performed in five stages of A, B, C, D, and E from the side farther from ${}_{R}CII$ (the reduction rate z is large).

[0102]

The simulation method of the present invention not only estimates the fuel consumption and/or CII rating at arbitrary one time point, for example, when a predetermined period elapses from the time of building of a vessel or the time of the latest docking of a vessel, but also estimates the fuel consumption and/or CII rating at arbitrary two or more time points (with a relatively long interval), for example, every year from the time of building of a vessel or the time of the latest docking of a vessel, over 5 years, at the time of the lapse of a first predetermined period (after 1 year 0 months), at the time of the lapse of a second predetermined period (after 2 years 0 months), at the time of the lapse of a third predetermined period (after 3 years 0 months), at the time of the lapse of a fourth predetermined period (after 4 years 0 months), and at the time of the lapse of a fifth predetermined period (after 5 years 0 months), or estimates the fuel consumption and/or CII rating at arbitrary two or more continuous time points (with a relatively short interval), for example, at the time of elapse of the first to 60th predetermined time periods, every month from the time of building of a vessel or the time of the latest docking of a vessel, over 5 years. In particular, the CII rating is evaluated on an annual CO_2

emission amount (yCO_2) and the annual fuel consumption (yFOC) may be determined as the sum of the monthly fuel consumption (mFOC) included in the year, so it is preferable to determine the fuel consumption every month for at least one year.

[0103]

When the fuel consumption and/or CII rating at arbitrary two or more time points or in an arbitrary period is estimated, the horsepower increase rate (PIR_r) due to hull roughness and the horsepower increase rate (PIR_f) due to hull fouling at a plurality of time points included therein may be calculated. For example, when PIR_r is determined, common PIR_{r_0} may be used, but PIR_{r_a} (FIR_{r_a} for further determining the same) may be calculated for each of a plurality of time points, PIR_{r_a1}, PIR_{r_a2}, PIR_{r_a3}, $\cdots$, and the like may be used, and PIR_{r1}, R_{r2}, PIR_{r3}, $\cdots$, and the like may be determined by summing these with PIR_{r_0}. The same applies to PIR_f and FIR_{f_a} for determining the same, and PIR_{f1}, R_{f2}, PIR_{f3}, $\cdots$ (PIR_{f_a1}, R_{f_a2}, PIR_{f_a3}, $\cdots$), and the like may be determined. Finally, a plurality of total horsepower increase rates PIR_{a1}, PIR_{a2}, PIR_{a3}, $\cdots$ may be determined by summing those values, respectively. In such an embodiment, a procedure (order of steps) is general where all of the desired multiple total horsepower increase rates PIR_{a1},

PIR_{a2}, PIR_{a3}, $\cdots$ are determined, followed by determining the respective fuel consumption (FOC, e.g. yFOC) and/or CII rating.

[0104]

The simulation method of the present invention not only determines the horsepower increase rate (PIR_r) due to hull roughness and the horsepower increase rate (PIR_f) due to hull fouling for any one paint or coating film formed from the paint with respect to hull roughness, for example a hydrolyzable anti-fouling paint (coating film), and finally estimates the fuel consumption and/or CII rating, but also determines PIR_r and PIR_f for arbitrary two or more paints (coating films) or for other conditions related to hull roughness or hull fouling, and finally estimates the fuel consumption and/or CII rating. Such an embodiment is preferable because it is possible to compare results of two or more paints (coating films), for example, a hydrolyzable anti-fouling paint (coating film), and other conditions related to hull roughness or hull fouling, and present a recommended one among them.

[0105]

When the fuel consumption and/or CII rating is estimated for arbitrary two or more paints (coating films) or other conditions related to hull roughness or hull

fouling, the horsepower increase rate (PIR_r) due to hull roughness and the horsepower increase rate (PIR_f) due to hull fouling may be calculated for each of the plurality of conditions. For example, when PIR_r is determined, PIR_{r1_0} and PIR_{r1_a} for the first condition (FIR_{r1_a} for determining the same), PIR_{r2_0} and PIR_{r2_a} for the second condition (FIR_{r2_a} for determining the same), PIR_{r3_0} and PIR_{r3_a} for the third condition (FIR_{r3_a} for determining the same), $\cdots$, and the like may be obtained. The same applies to PIR_f and FIR_{f_a} for determining the same, and PIR_{f1}, R_{f2}, PIR_{f3}, $\cdots$ (PIR_{f1_a}, R_{f2_a}, PIR_{f3_a}, $\cdots$), and the like may be determined. Finally, a plurality of total horsepower increase rates PIR_{1_a}, PIR_{2_a}, PIR_{3_a}, $\cdots$ may be determined by summing those values, respectively.

[0106]

The simulation method of the present invention may estimate the fuel consumption and/or CII rating for arbitrary two or more paints (coating films) or other conditions related to hull roughness or hull fouling at arbitrary two or more time points or in an arbitrary period by combining embodiments as described above.

[0107]

Examples of the conditions related to the hull roughness or the hull fouling other than the paint (coating

film) include the grade of base treatment (blasting) and the area thereof. In the case of combining conditions related to the paint with conditions related to the base treatment, four conditions, such as (i) the case of conventional anti-fouling paint/spot-blasting, (ii) the case of new anti-fouling paint/spot-blasting, (iii) the case of conventional anti-fouling paint/full-blasting, and (iv) the case of new anti-fouling paint/full-blasting, can be set. In such an embodiment, for example, it may be analyzed how the horsepower increase rates (PIR_a) of the conditions (ii) to (iv) differ when referenced to the condition (i), that is, how the horsepower reduction rate (reduction in the horsepower increase rate) of the conditions (ii) to (iv) changes with respect to the condition (i), how the fuel consumption (FOC) and/or CII rating changes with respect to the condition (i), etc.

[0108]

The analysis result using the simulation method of the present invention can be displayed by a table and/or a graph.

[0109]

-Program-

A program of the present invention is a program suitable for causing a computer to execute the simulation

method of the present invention. Those skilled in the art can understand matters that are not explicitly described in the following detailed description of the program of the present invention as the detailed description of the program of the present invention based on the common general technical knowledge related to the program and by referring to and appropriately replacing the matters related to the simulation method of the present invention described in the present specification. Conversely, matters related to the detailed description of the program of the present invention can also be referred to for matters related to the simulation method of the present invention. Note that the numbers of "steps" related to the program of the present invention described in the present specification and the drawings are for convenience, and it is also possible to perform processing by rearranging the order of steps or to perform processing of a plurality of steps substantially simultaneously.

[0110]

The programming language for designing and developing the program of the present invention is arbitrary, and programming languages common to those skilled in the art can be used. Although the program of the present invention can execute predetermined processing in a single computer, in a

system of the present invention as described later, it is preferable that the program is used to execute predetermined processing on the client terminal side and the server side connected to each other via a network. Therefore, it is preferable to use a programming language (for example, PHP) suitable for processing via such a network, for example, processing on a website.

[0111]

The program of the present invention is a program for causing a computer to execute a simulation method of a fuel consumption and/or CII rating of a vessel in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an arbitrary period, the program including a configuration causing the computer to execute:

a process of summing the separately determined horsepower increase rate (PIR_r) due to hull roughness and horsepower increase rate (PIR_f) due to hull fouling to obtain a total horsepower increase rate (PIR_a) (referred to as "step 1" in the present specification; see Fig. 3); and

a process of estimating the fuel consumption and/or CII rating based on the total horsepower increase rate (PIR_a) (referred to as "step 2" in the present

specification; see Fig. 3).

[0112]

·Step 1

Step 1 is a step of performing a process for summing PIR_r and PIR_f to obtain PIR_a according to Formula 13.

[0113]

The program of the present invention typically further includes a configuration causing a computer to execute, in order to determine the PIR_r used in step 1:

a process of calculating an initial frictional resistance increase rate (FIR_{r_0}) based on a measured value or an estimated value of the hull roughness (referred to as "step 3a" in the present specification);

a process of obtaining an initial horsepower increase rate (PIR_{r_0}) from the initial frictional resistance increase rate (FIR_{r_0}) (referred to as "step 3b" in the present specification);

a process of calculating a time-dependent frictional resistance increase rate (FIR_{r_a}) obtained by estimating and reflecting a change in hull roughness with time up to the arbitrary time point or within the arbitrary period (referred to as "step 4a" in the present specification);

a process of obtaining a time-dependent horsepower increase rate (PIR_{r_a}) from the time-dependent frictional

resistance increase rate (FIR_{r_a}) (referred to as "step 4b" in the present specification); and

a process of determining the PIR_r from the initial horsepower increase rate (PIR_{r_0}) and the time-dependent horsepower increase rate (PIR_{r_a}) (referred to as "step 5" in the present specification).

[0114]

·Step 3a

In step 3a, FIR_{r_0} can be calculated using the initial hull roughness and other necessary numerical values according to the first calculation method of FIR (Formulas 1 to 3), the second calculation method (Formulas 4 to 12), or other calculation methods as described above.

[0115]

In the case of calculating FIR_{r_0} according to the first calculation method of FIR (Formulas 1 to 3), the program of the present invention may use k_s (average roughness height) of the initial hull, L_{wL} (vessel length at the waterline) or L_{pp} (vessel length), ρ (density of fluid), v (representative flow velocity), l (representative length), μ (viscosity coefficient of fluid), C_{F0} (frictional resistance coefficient for water temperature reference value and salt concentration reference value), or the like, as an input numerical value or a numerical value described in

advance in the program itself or a database or the like that can be referred to by the program. For example, k_s of the initial hull can be acquired in advance by a BSRA-type roughness meter or a non-contact type laser displacement meter, and can be used by being input at the time of executing the program.

[0116]

In the case of calculating FIR_{r_0} according to the second calculation method of FIR (Formulas 4 to 12), the program of the present invention may use C (coefficient), A_r (hull roughness exposure projection area), or the like of the initial hull as an input numerical value or as a referable numerical value described in advance in the program itself, a database, or the like, or may use R (roughness height parameter), for example, Rc (average height of roughness curve elements), RSm (roughness wavelength parameter), and if necessary, Xs (length of each roughness curve element), τ_0 (shear stress calculated from mirror-finished test body, that is, smooth surface shear stress), τ (shear stress calculated from a test body when a hull paint is applied), δs_r (viscous sublayer thickness related to hull roughness), u^* (friction velocity), ρ (density), l_τ (wall surface friction length), ν (kinematic viscosity coefficient), y^+ (dimensionless distance), Ra

(arithmetic average roughness), or the like may be used. For example, Rc and RSm (three-dimensional roughness) of the initial hull are acquired in advance using a non-contact type laser displacement meter, and can be used by being input at the time of execution of the program.

[0117]

In step 3a (the first calculation method of FIR and the second calculation method of FIR), instead of the method of inputting necessary data at the time of executing the program as described above, an aggregate (database) of data acquired by a BSRA-type roughness meter or a non-contact type laser displacement meter in various coating specifications and the like is constructed in advance, and data such as k_s, Rc, and RSm corresponding to the input coating specifications and the like are extracted (estimated) with reference to the database, so that the program can use the extracted data.

[0118]

·Step 3b

In step 3b, PIR_{r_0} can be calculated according to Formula 14 using FIR_{r_0} calculated in step 3a and Form Factor.

[0119]

·Step 4a

In step 4a, FIR_{r_a} can be calculated according to the first calculation method of FIR (Formulas 1 to 3), the second calculation method (Formulas 4 to 12), or other calculation methods as described above using the hull roughness after a certain period of time elapses and other necessary numerical values.

[0120]

In the case of calculating FIR_{r_a} according to the first calculation method of FIR (Formulas 1 to 3), the program of the present invention may use k_s (average roughness height) of the hull after a certain period of time elapses, L_{wL} (vessel length at the waterline) or L_{pp} (vessel length), ρ (density of fluid), v (representative flow velocity), l (representative length), μ (viscosity coefficient of fluid), C_{F0} (frictional resistance coefficient for water temperature reference value and salt concentration reference value), or the like, as an input numerical value or a numerical value described in advance in the program itself or a database or the like that can be referred to by the program. For k_s of the hull after a certain period of time elapses, it is preferable that an aggregate (database) of data acquired by a BSRA-type roughness meter or a non-contact type laser displacement meter under various elapsed periods, paints, base

treatments, and other conditions is constructed in advance, and data of k_s corresponding to the input elapsed period, paint, base treatment, and other conditions are extracted with reference to the database, so that the program can use the extracted data. L_{wL} or L_{pp}, ρ, ν, l, μ, C_{F0}, and the like used in the embodiment according to the first calculation method of step 4a can be shared with those numerical values used in the embodiment according to the first calculation method of step 3a.

[0121]

In the case of calculating FIR_{r_a} according to the second calculation method of FIR (Formulas 4 to 12), the program of the present invention may use C (coefficient), A_r (hull roughness exposure projection area), or the like of the hull after a certain period of time elapses as an input numerical value or as a referable numerical value described in advance in the program itself, a database, or the like, or may use R (roughness height parameter), for example, Rc (average height of roughness curve elements), RSm (roughness wavelength parameter), and if necessary, Xs (length of each roughness curve element), τ_0 (shear stress calculated from mirror-finished test body, that is, smooth surface shear stress), τ (shear stress calculated from a test body when a hull paint is applied), δs_r (viscous sublayer thickness

related to hull roughness), u^* (friction velocity), ρ (density), l_τ (wall surface friction length), ν (kinematic viscosity coefficient)/s), y^+ (dimensionless distance), Ra (arithmetic average roughness), or the like may be used. For C and A_r, or R, for example, Rc, RSm, and other necessary numerical values related to the hull roughness after a certain period of time elapses, it is preferable that an aggregate (database) of data acquired by a non-contact type laser displacement meter under various elapsed periods, paints, base treatments, and other conditions is constructed in advance, and the necessary data corresponding to the input elapsed period, paints, base treatments, and other conditions are extracted with reference to the database, so that the program can use the extracted data. u^*, τ_0, ρ, l_τ, ν, y^+ and the like used in the embodiment according to the second calculation method of step 4a can be shared with those numerical values used in the embodiment according to the second calculation method of step 3a.

[0122]

·Step 4b

In step 4b, PIR_{r_a} may be calculated according to Formula 15 using FIR_{r_a} calculated in step 4a and Form Factor.

[0123]

·Step 5

In step 5, PIR_r can be obtained by PIR_{r_0} and PIR_{r_a}.

[0124]

The program of the present invention typically further includes a configuration causing a computer to execute, in order to determine the PIR_f used in step 1:

a process of calculating a time-dependent horsepower increase rate (PIR_{f_a}) obtained by estimating and reflecting hull fouling with time up to the arbitrary time point or within the arbitrary period to obtain the horsepower increase rate (PIR_f) due to hull fouling (referred to as "step 6" in the present specification).

[0125]

·Step 6

In step 6, PIR_f, that is, PIR_{f_a} can be calculated according to the first calculation method of PIR_f (Formulas 17 to 19) using the average speed loss (AveSL) or the like as described above, the second calculation method of PIR_f similar to the first calculation method of FIR, the third calculation method of PIR_f similar to the second calculation method of FIR, or the like.

[0126]

In the case of calculating PIR_f according to the first calculation method of PIR_f (Formulas 17 to 19), the

program of the present invention may use AveSL (average speed loss) or AvePIR (average horsepower increase rate) or $SL_{_1e}$, $SL_{_1b}$, $PIR_{_1e}$, $PIR_{_1b}$, or the like for calculating them as an input numerical value or as a numerical value described in advance in the program itself or a database or the like that can be referred to by the program. In order to be able to calculate the AveSL according to the fouling risk (FR) of the route along which a vessel navigates, it is preferable that an aggregate (database) of data acquired for more various elapsed periods, base treatments, and other conditions is constructed in advance for anti-fouling paint compositions having various performances and routes having various fouling risks (FR), data of the AveSL corresponding to the input elapsed periods, paints, base treatments, routes (fouling risks), and other conditions are extracted with reference to the database, so that the program can use the extracted data.

[0127]

In the case of calculating PIR_f according to the second calculation method of PIR_f, the program of the present invention may use the "estimated height of the fouling object shape" and the "fouling area" on the hull after a certain period of time elapses, L_{WL} (vessel length at the waterline) or L_{pp} (vessel length), ρ (density of the

fluid), v (representative flow velocity), l (representative length), μ (viscosity coefficient of the fluid), C_{F0} (frictional resistance coefficient for the water temperature reference value and the salt concentration reference value), or the like, as an input numerical value or a numerical value described in advance in the program itself or a database or the like that can be referred to by the program. By replacing K_s in Formula 1 with the "average estimated height of the fouling object shape", ΔC_F for the "hull fouling" can be calculated. Furthermore, the time-dependent friction increase rate FIR_{f_a} due to "hull fouling" is determined by using Formula 3, and finally, in Formula 15, the time-dependent horsepower increase rate PIR_{f_a} due to "hull fouling" is determined by using the time-dependent friction increase rate FIR_{f_a} due to "hull fouling" instead of the time-dependent friction increase rate FIR_{r_a} due to "hull roughness", and the time-dependent horsepower increase rate can be set as PIR_f. L_{wL} or L_{pp}, ρ, v, l, μ, C_{F0}, and the like used in the embodiment according to the second calculation method of step 6 can be shared with those numerical values used in the embodiment according to the first calculation method of step 3a (and the first calculation method of step 4a).

[0128]

In the case of calculating PIR_f according to the third calculation method of PIR_f, the program of the present invention may use the "exposed projection area of hull fouling" (A_f) and a coefficient depending thereon (C_f) on the hull after a certain period of time elapses as an input numerical value or as a numerical value described in advance in the program itself or a database or the like that can be referred to by the program, or may use R (roughness height parameter) for "hull fouling", for example, Rc (average height of roughness curve element), RSm (roughness wavelength parameter), and if necessary, Xs (length of each roughness curve element), τ_0 (shear stress calculated from mirror-finished test body, that is, smooth surface shear stress), τ (shear stress calculated from a test body when a hull paint is applied), δs_r (viscous sublayer thickness related to hull roughness), u^* (friction velocity), ρ (density), l_τ (wall surface friction length), ν (kinematic viscosity coefficient), y^+ (dimensionless distance), Ra (arithmetic average roughness), and the like. By replacing A_r in Formula 4 with A_f and replacing C with C_f, the time-dependent friction increase rate FIR_{f_a} due to "hull fouling" can be determined. C_f can be calculated by using, in Formula 5, the estimated height of the "fouling object" as R, the roughness wavelength parameter Rs_f of the "fouling

object" calculated in the same manner as in Formula 6 as RSm, and the FIR measured by the frictional resistance test for the "fouling object" calculated in the same manner as in Formula 7 as the FIR. In Formulas 8 to 11, A_f can be calculated by using each numerical value such as a parameter related to "hull fouling" or "fouling object" instead of each numerical value such as a parameter related to "hull roughness". For C and A_f, or R, for example, Rc, RS_f, and other necessary numerical values related to the hull fouling or fouling object after a certain period of time elapses, it is preferable that an aggregate (database) of data acquired by a non-contact type laser displacement meter under various elapsed periods, paints, base treatments, and other conditions is constructed in advance, and the necessary data corresponding to the input elapsed period, paints, base treatments, and other conditions are extracted with reference to the database, so that the program can use the extracted data. u^*, τ_0, ρ, l_τ, ν, y^+, and the like used in the embodiment according to the third calculation method of step 6 can be shared with those numerical values used in the embodiment according to the second calculation method of step 3a (and the second calculation method of step 4a).

[0129]

·Step 2

Step 2 is a step of performing a process for estimating the FOC (fuel consumption) and/or CII rating based on the PIR_a obtained in step 1.

[0130]

In the case of estimating the FOC at an arbitrary time point or in an arbitrary period, for example, mFOC (monthly fuel consumption) or yFOC (annual fuel consumption), the program of the present invention may include a process for estimating the FOC according to Formulas 20 and 21 using the dFOC (fuel consumption per day), the number of operating days, $PIR_{_b}$ (PIR of the benchmark period), $PIR_{_e}$ (PIR of the evaluation period), the number of elapsed months, etc. at a reference time point as an input numerical value or as a numerical value described in advance in the program itself or a database or the like that can be referred to by the program. The estimated FOC may be processed to be output to the outside or may be processed to be used (for example, Formula 21 and related formulas for yFOC are incorporated as yFOC in Formula 21 for estimating yCO_2) in other processes without being output to the outside according to the application of the program.

[0131]

The program of the present invention may further include a configuration for causing a computer to execute a

process of further estimating yCO_2 (annual CO_2 emission amount) from FOC at an arbitrary time point or in an arbitrary period estimated as described above in step 2. In this embodiment, the program of the present invention can execute a process of estimating yCO_2 by Formula 23 while using ($t\text{-}CO_2/t\text{-}Fuel$) (value defined by IMO for each fuel type) or the like as an input numerical value or a numerical value described in advance in the program itself or a database or the like that can be referred to by the program while using the estimated FOC. The estimated yCO_2 may be processed to be output to the outside or may be processed to be used (for example, Formula 23 and other related equations for yCO_2 are incorporated as yCO_2 in Formula 24 for calculating the ${}_{A}CII$ used to estimate the evaluation value (d) of CII) in other processes without being output to the outside according to the application of the program.

[0132]

The program of the present invention may further include a configuration for causing a computer to execute a process of further estimating CII rating from yCO_2 estimated as described above in step 2. In this embodiment, the program of the present invention can execute a process of calculating d (evaluation value of CII) by Formulas 24 to 27 using DWT (dead weight tonnage), GT (gross tonnage),

nautical distance, vessel type, nautical distance, $_{R}$CII (annual evaluation criteria of CII), CII_{ref} (CII average value for each vessel type), x (reduction rate from 2019), a and c (numerical values determined in advance for each vessel type), and the like as an input numerical value or a numerical value described in advance in the program itself or a database or the like that can be referred to by the program, while using the estimated yCO_2, and then estimating CII rating based on a predetermined standard (correspondence relationship between the evaluation value and the rating).

[0133]

The program of the present invention may be a program for estimating fuel consumption and/or CII rating at arbitrary one time point (for example, when a predetermined period elapses from the time of building of a vessel or the time of the latest docking of a vessel), or may be a program for estimating fuel consumption and/or CII rating at arbitrary two or more time points, or in an arbitrary period at two or more continuous time points with an arbitrary interval (for example, in a period over 5 years, every year to every month from the time of building of a vessel or the time of the latest docking of a vessel). In the latter embodiment, the program of the present invention may be configured to execute a process of outputting a plurality of

estimated values of fuel consumption and/or CII rating by using information such as numerical values corresponding to each of a plurality of time points by input or reference.

[0134]

The program of the present invention may be a program for estimating fuel consumption and/or CII rating under any one condition related to hull roughness and/or hull fouling (for example, hydrolyzable anti-fouling paint or other anti-fouling paint, or base treatment), or may be a program for estimating fuel consumption and/or CII rating under any two or more conditions related to hull roughness and/or hull fouling. In the latter embodiment, the program of the present invention may be configured to execute a process of outputting a plurality of estimated values of fuel consumption and/or CII rating by using information such as numerical values corresponding to a plurality of conditions related to hull roughness and/or hull fouling by input or reference.

[0135]

The program of the present invention may be a program including a configuration capable of presenting a recommended one among any two or more conditions related to hull roughness and/or hull fouling based on the fuel consumption and/or CII rating estimation results. For

example, in the case of combining conditions related to the paint with conditions related to the base treatment, four conditions, such as (i) the case of conventional anti-fouling paint/spot-blasting, (ii) the case of new anti-fouling paint/spot-blasting, (iii) the case of conventional anti-fouling paint/full-blasting, and (iv) the case of new anti-fouling paint/full-blasting, processing can be performed to estimate the fuel consumption and/or CII rating and present a combination of the lowest fuel consumption and/or the highest CII rating. In such an embodiment, it is preferable to further consider the route of the vessel to be simulated, that is, the fouling risk (FR), and present a combination of conditions under which the fuel consumption is estimated to be lowest and/or the CII rating is estimated to be highest in the route.

[0136]

The program of the present invention described above is preferably executed in a server in the system of the present invention described below, and in relation to such an embodiment, the program of the present invention may be referred to as “server program of the present invention”. In such an embodiment, it is preferable to use a program executed in the client terminal in order to combine with the server program of the present invention, and the program

therefor may be referred to as "client terminal program of the present invention".

[0137]

The client terminal program of the present invention is a program to be executed by a client terminal connected to a server via a network in order to execute the program of the present invention in the server, that is, in order to execute the program in combination with the server program of the present invention, the program including a configuration causing a computer to execute: a process of transmitting data of a measured value or an estimated value of hull roughness from the client terminal to the server; and a process of receiving data of a result calculated, obtained, determined, or estimated by the server and displaying the data on the client terminal. For the process of transmitting data of the measured value or the estimated value of the hull roughness in the server program of the present invention from the client terminal to the server and the process of receiving data of the result calculated, obtained, determined, or estimated by the server and displaying the data on the client terminal, it is possible to refer to the matters related to the simulation method of the present invention.

[0138]

The program of the present invention may be continuously recorded in a recording medium (for example, a CD-ROM, a USB memory, or the like) that can be read by a computer (client terminal and/or server) and is easy to transfer as an article, may be downloaded by the computer via a network such as the Internet and continuously or temporarily recorded in the computer, or may be recorded in a web server or the like in order to be downloaded by the computer via the network such as the Internet or to be used online. The program of the present invention may be a combination of programs in which the above-described embodiments related to recording are different depending on the configuration included therein.

[0139]

-System-

A system of the present invention is a system suitable for executing the simulation method of the present specification by using a client terminal and a server connected to each other via a network. Those skilled in the art can understand matters that are not explicitly described in the following detailed description of the system of the present invention as the detailed description of the system of the present invention based on the common general technical knowledge about the system and by referring to and

appropriately replacing matters related to the simulation method (and program) of the present invention described in this specification. Conversely, matters related to the detailed description of the system of the present invention can also be referred to for matters related to the simulation method (and the program) of the present invention.

[0140]

The system of the present invention is a system for executing, by using a client terminal and a server connected to each other via a network, simulation of a fuel consumption of a vessel in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an arbitrary period, wherein

the client terminal includes:

a means for transmitting at least data of a measured value or an estimated value of hull roughness to the server; and

a means for receiving and displaying data of a result calculated, obtained, determined, or estimated by the server,

the server includes:

a means for summing the separately determined

horsepower increase rate (PIR_r) due to hull roughness and horsepower increase rate (PIR_f) due to hull fouling to obtain a total horsepower increase rate (PIR_a); and

a means for estimating the fuel consumption and/or CII rating based on the total horsepower increase rate (PIR_a), and

simulation is executed by the server in response to transmission of the data from the client terminal, and a result of the simulation is displayed on the client terminal.

[0141]

Fig. 4 schematically illustrates a configuration example of a system 1 of the present invention.

[0142]

A client terminal 100 includes an input means 110, a client-terminal-side transmission/reception means 115, an output means 120, and the like. The client terminal 100 may be of any form such as a desktop personal computer, a notebook personal computer, a tablet, or a smartphone. As the input means 110, an input device such as a keyboard and a mouse, a monitor of a personal computer for displaying an input screen, a display in a tablet, a smartphone, or the like can be used. As the output means 120, a monitor of a personal computer, a display in a tablet, a smartphone, or

the like for displaying a simulation result can also be used. The input means 110 may be integrated like a touch panel in which the direct operation can directly performed on the display. The displays of the input means 110 and the output means 120 can be shared, and the input screen and the output screen can be displayed at an appropriate location at an appropriate timing. As the client-terminal-side transmission/reception means 115, a wired or wireless network device can be used. Data of the measured value or the estimated value of the hull roughness input by the input means 110 is transmitted to a server 200 by the transmission/reception means 115 via a network 10 such as the Internet, an intranet, or a local area network.

[0143]

The server 200 includes an arithmetic processing means 210, a server-side transmission/reception means 215, and the like. As the server-side transmission/reception means 215, a wired or wireless network device can be used. Upon receiving the data transmitted from the client terminal 110, the server 200 executes, by the arithmetic processing means 210, simulation of the fuel consumption of the vessel in consideration of the horsepower increase rate (PIR_r) due to hull roughness and the horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an

arbitrary period based on the simulation method of the present invention. The arithmetic processing means 210 includes at least a processing means for summing up the separately determined PIR_r and PIR_f to obtain PIR_a, and a means for estimating the fuel consumption and/or CII rating based on PIR_a. Such an arithmetic processing means 210 can be constructed by using a storage device such as a memory or a hard disk in which the program of the present invention is permanently (perpetually) or non-permanently (temporarily) stored, and an arithmetic processing device such as a central processing unit (CPU) operatively connected to each other. The storage device may also permanently (perpetually) or non-permanently (temporarily) store the data received from the client terminal, the data of the result calculated, obtained, determined, or estimated by the simulation method of the present invention, the data referred to for implementing the simulation method of the present invention, and the like. The simulation result by the server 200 is transmitted to the client-side terminal 100 via the network 10 by the server-side transmission/reception means 215 and displayed on the output means 120.

[0144]

The arithmetic processing means 210 can include a

means for realizing various processes corresponding to the embodiment of the program of the present invention stored in the storage device. For example, the server 200 can further include a means for calculating FIR_{r_0} based on data of the measured value or the estimated value of the hull roughness received from the client terminal 100 by the arithmetic processing means 210 and a storage device storing the program of the present invention (steps 3a, 3b, 4a, 4b, and 5) operably connected thereto, a means for obtaining PIR_{r_0} from FIR_{r_0}, a means for calculating FIR_{r_a} obtained by estimating and reflecting a change in hull roughness with time up to an arbitrary time point or within an arbitrary period, a means for obtaining PIR_{r_a} from FIR_{r_a}, and a means for determining PIR_r from PIR_{r_0} and PIR_{r_a}. The server 200 can further include a means for calculating PIR_{f_a} obtained by estimating and reflecting hull fouling with time up to an arbitrary time point or within an arbitrary period by the arithmetic processing means 210, that is, an arithmetic processing device and a storage device storing the program of the present invention (step 6) connected to the arithmetic processing device in an accessible manner, to determine PIR_f.

[0145]

·FIR calculation form

Fig. 5 schematically illustrates an embodiment of an "FIR calculation form" in the client terminal. This embodiment corresponds to an embodiment in which FIR_{r_0} is calculated by the "second calculation method of FIR" (Formulas 4 to 12) on the server side, and various types of information regarding the hull necessary for this purpose are input from the form.

[0146]

"Rc" (average height of the roughness curve element at the initial stage of the hull) and "RSm" (wavelength parameter of the roughness curve element at the initial stage of the hull) are the numerical values used in Formula 5. For both Rc and RSm, a numerical value measured by a three-dimensional roughness meter (laser displacement meter or the like) can be input.

[0147]

The "vessel length" is a numerical value for estimating FIR of the entire vessel by estimating FIR for each specific position from Rc, RSm, and δs_r for each hull position and then integrating the FIR with the "vessel length" and the area estimated from the "vessel length". For the vessel length, a numerical value that can be searched through the Internet or the like can be input.

[0148]

The "reference velocity" is used in Formulas 9 and 10, and is a numerical value necessary for calculating δs_r by Formula 11 and further calculating A_r by Formula 8. As the reference velocity, a numerical value that can be analyzed by an automatic identification system (AIS) can be input. The reference velocity is generally in a range of 0 to 30 knots (kt) and preferably in a range of 0 to 26 knots. The reference velocity can be used to calculate FIR_{r_0}, and can be used to obtain FIR_{r_a} by simulation (by referring to a database). When the reference velocity is used for calculating FIR_{r_a}, the reference velocity may be used in the FIR calculation form or may be called and used in the next PIR calculation form.

[0149]

It is preferable that other numerical values related to the "second calculation method of FIR" (Formulas 4 to 12), for example, "C" (Formula 4, Formula 5), "τ" and "τ_0" (Formula 7), "ρ" (Formula 9), "ν" (Formula 10), "y^+" (Formula 11), and the like are not input from a form each time of simulation, but are stored in advance in a storage device included in the server 200 based on a previous test result or the like, and can be referred to and used by an arithmetic processing device if necessary.

[0150]

By clicking the “BSRA option” button, the “FIR calculation form” corresponding to the embodiment in which FIR_{r_0} is calculated by the “second calculation method of FIR” (Formulas 4 to 12) can be switched to the “FIR (BSRA) calculation form” corresponding to the embodiment in which FIR_{r_0} is calculated by the “first calculation method of FIR” (Formulas 1 to 3), or can be displayed in a pop-up format.

[0151]

Fig. 6 schematically illustrates an embodiment of the “FIR (BSRA) calculation form” in the client terminal corresponding to the embodiment in which FIR_{r_0} is calculated by the “first calculation method of FIR” (Formulas 1 to 3).

[0152]

The “vessel length” is a numerical value corresponding to L_{wL} in Formula 1, and a numerical value that can be searched through the Internet or the like can be input.

[0153]

“k_s” is a numerical value used to calculate “ΔC_F” together with “L_{wL}” and “Re” (Reynolds number) in Formula 1. As k_s, a numerical value measured by a BSRA roughness meter or a three-dimensional roughness meter (laser displacement meter or the like) can be input.

[0154]

The "reference velocity" is a numerical value corresponding to "v" (representative flow velocity) used to calculate Re in Formula 2, and a numerical value that can be analyzed by AIS can be input.

[0155]

By clicking the "BSRA option release" button, the "FIR calculation form" corresponding to the embodiment in which FIR_{r_0} is calculated by the "first calculation method of FIR" (Formulas 1 to 3) can be switched to the "FIR calculation form" corresponding to the embodiment in which FIR_{r_0} is calculated by the "second calculation method of FIR" (Formulas 4 to 12), or the "FIR (BSRA) calculation form" in a pop-up format can be closed.

[0156]

When a predetermined numerical value is input into the input form illustrated in Fig. 5 or 6 and then the "FIR calculation" button is clicked, data of the numerical value is transmitted to the server 200 via the network by the client-terminal-side transmission/reception means 115. The server 200 that has received the data by the server-side transmission/reception means 215 executes the process (step 3a in Fig. 3) of the "second calculation method of FIR" (Formulas 4 to 12) or the "first calculation method of FIR" (Formulas 1 to 3) of the program of the present invention by

the arithmetic processing means 210 to calculate FIR_{r_0}. FIR_{r_0} and/or FIR_{r_a} when the input numerical value of the "reference velocity" is varied within a predetermined range (for example, at 0 to 30 knots) may be calculated as a simulation. The data of FIR_{r_0} and/or FIR_{r_a} is transmitted to the client terminal 100 via the network by the server-side transmission/reception means 215. The client terminal 100 that has received the data by the client-side reception means 115 displays the calculation result of FIR_{r_0} and/or FIR_{r_a} by the output means 120, for example, by a display.

[0157]

Fig. 7 schematically illustrates an embodiment of a display screen of a calculation result of FIR_{r_0}. Together with FIR_{r_0} (and/or FIR_{r_a}) corresponding to the input reference velocity "12.5" knots, FIR_{r_0} (and/or FIR_{r_a}) when the reference velocity is varied within a range of 1 to 30 knots is also calculated and displayed in a table and graph (continuous curve). A check box for passing the simulation result of FIR_{r_0} (and/or FIR_{r_a}) to the calculation of the PIR is provided if necessary.

[0158]

·PIR calculation form

Fig. 8 schematically illustrates an embodiment of a "PIR calculation form" in the client terminal. This

embodiment corresponds to an embodiment in which, on the server side, PIR_{r_0} and PIR_{r_a} are calculated from FIR_{r_0} and FIR_{r_a}, respectively (Formulas 14 and 15), PIR_r is determined based on PIR_{r_0} and PIR_{r_a}, whereas PIR_f is calculated by the "first calculation method for PIR_f" (Formulas 17 to 19), and PIR_a is calculated by summing PIR_r and PIR_f (Formula 13). The information regarding the hull, the operating information and the information regarding the anti-fouling paint product required for this embodiment are made available by entry from the form or by reference to the database. From the calculated PIR_a, FOC is finally calculated (Formulas 22 to 25). A check box for estimating CII rating from the calculated FOC is provided if necessary (Formulas 26 to 29).

[0159]

·Hull information

The "vessel type" and the "size" are items related to Formulas 26 to 29 used for estimating CII rating. The "vessel type" may be selectable from: (1) a bulk-carrier, (2) a container-ship, (3) a tanker, (4) a general cargo ship (General cargo), (5) a refrigerated cargo ship (Refrigerated cargo), (6) a combination carrier, (7) an LNG carrier (LNG), (8) a gas ship (LPG/CNG) (LPG), (9) a RoRo cargo ship (Ro-ro cargo), (10) an automobile cargo ship (vehicle carrier),

(11) a RoRo passenger ship (RO-PAX ferry), (12) a cruise ship (Cruise passenger ship). For the “size”, GWT (dead weight tonnage) may be input when the “vessel type” is the above (1) to (8), and GT (gross tonnage) may be input when the “vessel type” is the above (9) to (12). Note that, when it is not necessary to estimate the CII rating, the input of “vessel type” and “size” can be omitted.

[0160]

·Operating information in reference year

The “fuel type” is an item related to Formula 25 (t-Fuel) used for calculating FOC, and may be selectable from: (1) heavy fuel oil, (2) light fuel oil, (3) diesel/gas oil, (4) LPG (propane), (5) LPG (butane), (6) LNG (LPG), (7) methanol, and (8) ethanol.

[0161]

The “fuel consumption” (MT/day) and “number of operating days” (day/year) are numerical values related to Formula 23, and a numerical value that can be grasped by a company/person that operates a vessel (vessel owner) or the like can be input.

[0162]

The “nautical distance” (NM (nautical miles)/year) is a numerical value related to Formula 26 used for estimating the CII rating, and a numerical value that can be grasped by

a company/person that operates a vessel (vessel owner) or the like can be input. Note that, when it is not necessary to estimate the CII rating, the input of "navigation distance" can be omitted.

[0163]

The "number of elapsed years" (year, from delivery or last full-blasting) is a numerical value related to Formula 24 (the number of elapsed months) used for calculating the FOC, and a numerical value that can be grasped by a company/person that operates a vessel (vessel owner) or the like can be input.

[0164]

·Anti-fouling paint product information

The "service life" is a numerical value related to the "benchmark period" and the "evaluation period" of Formula 23 used for calculating the FOC. The "service life" can be set according to the type of anti-fouling paint, the coating method, and the like, and can be set to, for example, 5 years, which is set in a range of 1 to 5 years.

[0165]

For the "coating area", for example, the hull is divided into a flat bottom part (FB), a vertical bottom part (VB), and a boot top part (BT), and the coating area of each part can be input. As described above as a preferred

embodiment of the FIR, when the hull is divided as described above and the FIR of the entire hull is obtained, the input coating area of each part can be used.

[0166]

In each of the "conventional anti-fouling paint" and the "new anti-fouling paint", a paint used for simulation can be selected and input for each part of the hull. The type of the anti-fouling paint is not particularly limited, and various known anti-fouling paints and anti-fouling paints available as products can be selected, and examples thereof include various silicone elastomer-based rod paints, metal (zinc) acrylic polymer-based hydrolyzable type anti-fouling paints, silyl methacrylate polymer-based hydrolyzable type anti-fouling paints, low VOC special polyester polymer-based hydrolyzable type anti-fouling paints, and self-polishing anti-fouling paints. As the "conventional anti-fouling paint", one that is currently applied to the hull to be simulated can be selected. The "new anti-fouling paint" can be selected from anti-fouling paints having properties that can improve fuel consumption and CII rating as compared to "conventional anti-fouling paint". The "conventional anti-fouling paint" and the "new anti-fouling paint" may be classified into three types, for example, economy grade (products focusing on economic

efficiency), middle grade (average products in the market), and high grade (high-performance products), and may be selected from the three types.

[0167]

Other numerical values and information related to the calculation of FOC and the estimation of CII rating, for example, "Form Factor" (Formulas 14 to 16), "AveSL" and "AvePIR" (Formulas 17 to 19), "t-CO_2" and "t-Fuel" (Formula 25), "z" (Formula 27), "a" and "b" (Formula 28), and the like are preferably stored in advance in a storage device included in the server 200 based on a previous test result or the like, instead of being input from a form each time of simulation, and can be referred to and used by an arithmetic processing device if necessary. In particular, it is important that information regarding how FIR_{r_a} and FIR_{f_a} change with time for various "conventional anti-fouling paints" and "new anti-fouling paints" is stored in a storage device included in the server 200 in advance so that the information can be used when the present invention is implemented.

[0168]

When a predetermined numerical value or information is input in the input form illustrated in Fig. 8 and then the "PIR calculation" button is clicked, data of the

numerical value and the information is transmitted to the server 200 via the network by the client-terminal-side transmission/reception means 115. The server 200 that has received the data by the server-side transmission/reception means 215 executes, by the arithmetic processing means 210, the process of the "calculation method of PIR_{r_0} and PIR_{r_a}" (Formulas 14 and 15) of the program of the present invention (steps 3b and 4b in Fig. 3), calculates PIR_{r_0} and PIR_{r_a}, and then executes a process of calculating PIR_r (Formula 13, step 5 in Fig. 3). Numerical values and numerical data regarding the input "anti-fouling paint product information" are also transmitted to the server 200 via the network by the client-terminal-side transmission/reception means 115. The server 200 that has received the data by the server-side transmission/reception means 215 executes a process of calculating PIR_{f_a}, that is, PIR_f (step 6 in Fig. 3) by the arithmetic processing means 210 according to the "first calculation method of PIR_f" (Formulas 17 to 19), the "second calculation method of PIR_f", or the "third calculation method of PIR_f" of the program of the present invention. Subsequently, a process of calculating PIR_a by summing PIR_r and PIR_f determined by these processes (Formula 13, step 1 in Fig. 3) is executed. Finally, FOC is calculated based on PIR_a and CII rating is estimated if necessary. The data of

FOC and CII rating is transmitted to the client terminal 100 via the network by the server-side transmission/reception means 215. The client terminal 100 that has received the data by the client-side reception means 115 displays the simulation results of FOC and CII rating by the output means 120, for example, by a display.

[0169]

Fig. 9 schematically illustrates an embodiment of a display screen of FOC and CII rating simulation results. In the present embodiment, simulation results of the factor related to the hull roughness (roughness factor: FIR, Form Factor, PIR) and the factor related to the hull fouling (fouling factor: average speed loss, average PIR) are shown in comparison for (a) FOC, (b) number of operating days, and four conditions: (c) the case of applying a conventional anti-fouling paint after spot-blasting, (d) the case of applying a new anti-fouling paint after spot-blasting, (e) the case of applying a conventional anti-fouling paint after full-blasting, and (f) the case of applying a new anti-fouling paint after full-blasting. As the horsepower reduction rate (PRR), the PRR of the condition (d) with respect to the condition (c), the PRR of the condition (e) with respect to the condition (c), and the PRR of the condition (f) with respect to the condition (c) are shown as

(g), (h), and (i), respectively. In tables and graphs, initial FOC just after dry dock is shown as initial performance simulation, and FOC at 1 to 5 years is shown as long-term performance simulation. Furthermore, based on the simulation results of these FOCs, the CII rating is shown with a five-grade evaluation of A (good) to E (bad). Finally, the total fuel consumption, the total fuel consumption reduction amount, and the total carbon dioxide emission reduction amount in the service life (5 years) are shown.

[0170]

Such a simulation result can be utilized as a determination material for the next dry dock, such as whether to change the type of anti-fouling paint or to perform full-blasting, a confirmation and countermeasure material for CII rating after 1 to 5 years, a material for reviewing operation conditions, and the like. These pieces of information are also transmitted to the client terminal 100 via the network by the server-side transmission/reception means 215, and can be displayed by the output means 120 by the client terminal 100 that has received the data by the client-side reception means 115.

[0171]

The system of the present invention may be an

embodiment in which a single entity prepares (produces, temporarily accepts, etc.) a client terminal and a server, or may be an embodiment in which a plurality of entities prepares a client terminal and a server. For example, an entity that prepares a client terminal on its own or in response to recruitment or recommendation by a server preparer (for example, the client terminal program of the present invention is downloaded via a network and recorded in a computer-readable recording medium included in the client terminal) and then uses the client terminal may be different from an entity that prepares a server (for example, the server program of the present invention is created and recorded in a computer-readable recording medium included in a server which is borrowed) and recruits a user of the client terminal by promotion, advertisement, or the like or recommends a customer to use the client terminal. Regardless of whether the entities that prepare a client terminal and a server are the same or different, the system of the present invention can be produced (constructed). The entity that prepares a server creates a client program and causes the entity that prepares a client terminal to download the program via the network, whereby the entity that prepares a server can be a manufacturer of the system of the present invention.

CLAIMS

[Claim 1]

A simulation method including a step of estimating a fuel consumption and/or CII rating of a vessel in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an arbitrary period, the simulation method comprising:

summing the separately determined PIR_r and PIR_f to obtain a total horsepower increase rate (PIR_a), and then finally estimating the fuel consumption and/or CII rating based on the total horsepower increase rate (PIR_a).

[Claim 2]

The simulation method according to claim 1, wherein the PIR_r is based on:

an initial horsepower increase rate (PIR_{r_0}) obtained from an initial frictional resistance increase rate (FIR_{r_0}) calculated based on a measured value or an estimated value of hull roughness, and

a time-dependent horsepower increase rate (PIR_{r_a}) obtained from a time-dependent frictional resistance increase rate (FIR_{r_a}) obtained by estimating and reflecting a change in hull roughness with time up to the arbitrary

time point or within the arbitrary period.

[Claim 3]

The simulation method according to claim 1 or 2, wherein the PIR_f is

a time-dependent horsepower increase rate (PIR_{f_a}) obtained by estimating and reflecting hull fouling with time up to the arbitrary time point or within the arbitrary period.

[Claim 4]

The simulation method according to any one of claims 1 to 3, wherein the initial frictional resistance increase rate (FIR_{r_0}) and the time-dependent frictional resistance increase rate (FIR_{r_a}) due to hull roughness are calculated by Townsin's formula of ITTC 1978.

[Claim 5]

The simulation method according to any one of claims 1 to 4, wherein the initial frictional resistance increase rate (FIR_{r_0}) and the time-dependent frictional resistance increase rate (FIR_{r_a}) due to hull roughness are calculated based on

a projection area (A_r) of roughness exposed from a

viscous sublayer thickness (δs_r) related to hull roughness.

[Claim 6]

The simulation method according to claim 5, wherein the forward projection area (A_r) related to hull roughness is calculated based on at least a height parameter (R) and a wavelength parameter (RSm) of the hull roughness.

[Claim 7]

The simulation method according to claim 6, wherein a size of a wall surface friction length (l_τ) used for calculating the viscous sublayer thickness (δs_r) related to hull roughness is changed by a correlation between a frictional resistance increase rate (FIR_{r_b}) obtained in a frictional resistance range of at least two arbitrary frictional resistance tests and an exposed roughness projection area (A_r).

[Claim 8]

The simulation method according to claim 6, wherein the viscous sublayer thickness (δs_r) related to hull roughness is changed according to a frictional resistance value for each position.

[Claim 9]

The simulation method according to any one of claims 1 to 8, wherein the horsepower increase rate (PIR_f) due to hull fouling is calculated based on an average speed loss (AveSL) or an average horsepower increase rate (AvePIR).

[Claim 10]

The simulation method according to claim 9, wherein the average speed loss (AveSL) or average horsepower increase rate (AvePIR) is calculated according to a fouling risk (FR) of a route along which a vessel navigates.

[Claim 11]

The simulation method according to any one of claims 1 to 10, wherein the time-dependent horsepower increase rate (PIR_{f_a}) due to hull fouling is calculated by Townsin's formula of ITTC 1978 based on an estimated height of a fouling object shape and a fouling area.

[Claim 12]

The simulation method according to any one of claims 1 to 11, wherein the time-dependent horsepower increase rate (PIR_{f_a}) due to hull fouling is calculated based on

a time-dependent frictional resistance increase rate

(FIR_{f_a}) calculated based on a projection area (A_f) of an exposed fouling shape from an estimated height, a wavelength, and a viscous sublayer thickness (δs_f) related to a fouling object.

[Claim 13]

The simulation method according to claim 12, wherein a size of a wall surface friction length (l_τ) used for calculating the viscous sublayer thickness (δs_f) related to the fouling object is changed by a correlation between a frictional resistance increase rate (FIR_{f_b}) obtained in a frictional resistance range of at least two arbitrary frictional resistance tests and an exposed roughness projection area (A_f).

[Claim 14]

The simulation method according to any one of claims 1 to 13, comprising a step of estimating a fuel consumption and/or CII rating in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at two or more arbitrary time points or in an arbitrary period.

[Claim 15]

The simulation method according to any one of claims 1 to 14, comprising a step of estimating a fuel consumption and/or CII rating in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling for two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling.

[Claim 16]

The simulation method according to any one of claims 1 to 15, comprising a step of presenting a recommended one of two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling.

[Claim 17]

A program for causing a computer to execute a simulation method of a fuel consumption and/or CII rating of a vessel in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an arbitrary period, the program comprising a configuration causing the computer to execute:

a process of summing the separately determined horsepower increase rate (PIR_r) due to hull roughness and

horsepower increase rate (PIR_f) due to hull fouling to obtain a total horsepower increase rate (PIR_a); and

a process of estimating the fuel consumption and/or CII rating based on the total horsepower increase rate (PIR_a).

[Claim 18]

The program according to claim 17, further comprising a configuration causing a computer to execute, in order to determine the horsepower increase rate (PIR_r) due to hull roughness:

a process of calculating an initial frictional resistance increase rate (FIR_{r_0}) based on a measured value or an estimated value of the hull roughness;

a process of obtaining an initial horsepower increase rate (PIR_{r_0}) from the initial frictional resistance increase rate (FIR_{r_0});

a process of calculating a time-dependent frictional resistance increase rate (FIR_{r_a}) obtained by estimating and reflecting a change in hull roughness with time up to the arbitrary time point or within the arbitrary period;

a process of obtaining a time-dependent horsepower increase rate (PIR_{r_a}) from the time-dependent frictional resistance increase rate (FIR_{r_a}); and

a process of determining the PIR_r from the initial horsepower increase rate (PIR_{r_0}) and the time-dependent horsepower increase rate (PIR_{r_a}).

[Claim 19]

The program according to claim 17 or 18, further comprising a configuration causing a computer to execute, in order to determine the horsepower increase rate (PIR_f) due to hull fouling:

a process of calculating a time-dependent horsepower increase rate (PIR_{f_a}) obtained by estimating and reflecting hull fouling with time up to the arbitrary time point or within the arbitrary period to obtain the horsepower increase rate (PIR_f) due to hull fouling.

[Claim 20]

The program according to any one of claims 17 to 19, comprising a configuration capable of estimating a fuel consumption and/or CII rating in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at two or more arbitrary time points or in an arbitrary period.

[Claim 21]

The program according to any one of claims 17 to 20, comprising a configuration capable of estimating a fuel consumption and/or CII rating in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling for two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling.

[Claim 22]

The program according to any one of claims 17 to 21, comprising a configuration capable of presenting a recommended one of two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling based on an estimated result of the fuel consumption and/or CII rating.

[Claim 23]

A program for causing a client terminal connected to a server via a network to execute the program according to any one of claims 17 to 22 in the server, the program comprising a configuration causing a computer to execute:

a process of transmitting data of a measured value or an estimated value of hull roughness from the client terminal to the server; and

a process of receiving data of a result calculated, obtained, determined, or estimated by the server and displaying the data on the client terminal.

[Claim 24]

A computer-readable recording medium on which the program according to any one of claims 17 to 22 is continuously recorded.

[Claim 25]

A computer-readable recording medium on which the program according to claim 23 is continuously recorded.

[Claim 26]

A system for executing, by using a client terminal and a server connected to each other via a network, simulation of a fuel consumption of a vessel in consideration of a horsepower increase rate (PIR_r) due to hull roughness and a horsepower increase rate (PIR_f) due to hull fouling at an arbitrary time point or in an arbitrary period, wherein

the client terminal includes:

a means for transmitting at least data of a measured value or an estimated value of hull roughness to the server;

and

a means for receiving and displaying data of a result calculated, obtained, determined, or estimated by the server,

the server includes:

a means for summing the separately determined horsepower increase rate (PIR_r) due to hull roughness and horsepower increase rate (PIR_f) due to hull fouling to obtain a total horsepower increase rate (PIR_a); and

a means for estimating the fuel consumption and/or CII rating based on the total horsepower increase rate (PIR_a), and

simulation is executed by the server in response to transmission of the data from the client terminal, and a result of the simulation is displayed on the client terminal.

[Claim 27]

The system according to claim 26, wherein the server further includes:

a means for calculating an initial frictional resistance increase rate (FIR_{r_0}) based on a measured value or an estimated value of the hull roughness received from the client terminal;

a means for obtaining an initial horsepower increase rate (PIR_{r_0}) from the initial frictional resistance increase rate (FIR_{r_0});

a means for calculating a time-dependent frictional resistance increase rate (FIR_{r_a}) obtained by estimating and reflecting a change in hull roughness with time up to the arbitrary time point or within the arbitrary period;

a means for obtaining a time-dependent horsepower increase rate (PIR_{r_a}) from the time-dependent frictional resistance increase rate (FIR_{r_a}); and

a means for determining a horsepower increase rate (PIR_r) due to hull roughness from the initial horsepower increase rate (PIR_{r_0}) and the time-dependent horsepower increase rate (PIR_{r_a}).

[Claim 28]

The system according to claim 26 or 27, further comprising

a means for calculating a time-dependent horsepower increase rate (PIR_{f_a}) obtained by estimating and reflecting hull fouling with time up to the arbitrary time point or within the arbitrary period to obtain the horsepower increase rate (PIR_f) due to hull fouling.

[Claim 29]

The system according to any one of claims 26 to 28, wherein data specifying two or more arbitrary time points or an arbitrary period is transmitted from the client terminal to the server,

the server executes the simulation for two or more arbitrary time points or an arbitrary period in correspondence with the data, and

a result of the simulation is displayed on the client terminal.

[Claim 30]

The system according to any one of claims 26 to 29, wherein data specifying two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling is transmitted from the client terminal to the server,

the server executes the simulation for two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling in correspondence with the data, and

a result of the simulation is displayed on the client terminal.

[Claim 31]

The system according to any one of claims 26 to 30, wherein the server presents a recommended one of two or more hydrolyzable anti-fouling paints or other conditions related to hull roughness or hull fouling based on an estimated result of the fuel consumption and/or CII rating, and

a simulation result including the recommendation is displayed on the client terminal.

[Claim 32]

The system according to any one of claims 26 to 31, wherein the server is operated by the computer-readable recording medium according to claim 24.

[Claim 33]

The system according to any one of claims 26 to 32, wherein the client terminal is operated by the computer-readable recording medium according to claim 25.