

A SHIP CARBON INTENSITY INDICATOR LEVEL AUXILIARY DECISION SUPPORT SYSTEM AND METHOD

Technical field

The present invention relates to the technical field of ship energy conservation and emission reduction, in particular to a ship carbon intensity indicator level auxiliary decision support system and method.

Background Technique

With the increasing pressure to address global climate change, the International Maritime Organization (IMO) formulated a greenhouse gas (GHG) emission reduction strategy in 2018. In IMO's initial strategy, the primary goal is the reduction of ship carbon intensity, which will be achieved through progressively tightening energy efficiency and emission reduction requirements. In June 2021, the Marine Environment Protection Committee (MEPC) adopted new amendments to the International Maritime Organization (IMO) MARPOL Convention. The new additions include new energy efficiency requirements—the Existing Ship Energy Efficiency Index (EEXI) and the Carbon Intensity Indicator (CII), which are important measures to reduce greenhouse gas (GHG) emissions from shipping.

In response to the increasingly stringent emission reduction demands in the shipping industry, it has become imperative to cut carbon emissions during ship operations. To mitigate the environmental impact of greenhouse gas emissions, decarbonization mandates have been established across various sectors. For container ship operations, the implementation of the Carbon Intensity Indicator (CII) regulation has led to progressively stricter CII targets. A ship's CII Level is assessed annually based on its fuel consumption and operational profile. Within the mandatory CII framework, ships are assigned one of five efficiency grades—A, B, C, D, or E—based on their calculated CII value. Furthermore, the required CII benchmark becomes more rigorous each year. Starting in 2023, ships receiving a D or E Level are considered non-compliant and insufficiently proactive in addressing climate change. Owners of such ships will be required to revise and update their Ship Energy

Efficiency Management Plan (SEEMP) to improve the ship's CII Level.

Consequently, ship operators must develop and implement sound strategies to prevent a decline in their CII level, which would trigger a series of operational penalties.

Summary of the Invention

To address issues such as operational penalties affecting ship operation due to a decline in a ship's Carbon Intensity Indicator (CII) Level, the present invention provides a Ship Carbon Intensity Indicator Level Auxiliary Decision Support System. By employing specific calculation and judgment methods, the system can effectively enhance the monitoring and prediction capabilities of a ship's CII value, avoid the phenomenon of ship violations caused by exceeding the CII Level limit, and facilitate the advance formulation of reasonable ship sailing plans. The present invention also relates to a Ship Carbon Intensity Indicator Level Auxiliary Decision Support Method.

The technical solution of the present invention is as follows:

A ship carbon intensity indicator level auxiliary decision support system comprises an information acquisition module, a data quality monitoring module, a fuel consumption model building module, a level monitoring module, a level prediction module, a level auxiliary decision module, and a human-machine interaction module; wherein the human-machine interaction module is respectively connected to the information acquisition module, the data quality monitoring module, the fuel consumption model building module, the level monitoring module, the level prediction module, and the level auxiliary decision module; and the information acquisition module, the data quality monitoring module, the fuel consumption model building module, the level monitoring module, the level prediction module, and the level auxiliary decision module are connected in sequence;

the information acquisition module collects historical voyage data of the ship, as well as future voyage plan data and a target carbon intensity indicator value of the ship selected by a user via the human-machine interaction module;

the data quality monitoring module comprises a data quality anomaly alert sub-module and a voyage plan anomaly alert sub-module, wherein the data quality anomaly alert sub-module automatically determines whether sailing fuel consumption data, berthing fuel consumption data, and sailing distance data in the historical voyage data are abnormal, and triggers a historical voyage

data quality anomaly alert if abnormality is determined; and the voyage plan anomaly alert sub-module automatically determines whether a sequence of ports of call in a current voyage of the ship is consistent with a sequence of ports of call in the future voyage plan, and triggers a non-compliance with voyage plan execution alert if they are inconsistent;

the fuel consumption model building module excludes the abnormal historical voyage data determined by the data quality anomaly alert sub-module, and builds a sailing fuel consumption model and a berthing fuel consumption model based on the remaining historical voyage data;

the level monitoring module calculates a total sailing distance for a current calendar year of the ship and for each voyage within that year based on the remaining historical voyage data, calculates a total fuel consumption for the ship for that year and for each voyage within that year based on the sailing fuel consumption model and the berthing fuel consumption model, calculates a carbon intensity indicator value for the ship for that year and for each voyage within that year based on the total fuel consumption and the total sailing distance, and determines a carbon intensity indicator level based on the carbon intensity indicator value;

the level prediction module automatically determines whether the sequence of ports of call for the ship's current voyage, as monitored by the voyage plan anomaly alert sub-module, is being executed according to the future voyage plan; if not, no prediction result is output; if so, it outputs a predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those future years;

the level auxiliary decision module monitors the predicted carbon intensity indicator values for each future year in real-time, and automatically determines whether the predicted carbon intensity indicator value exceeds a target carbon intensity indicator value selected by the user, and if the predicted carbon intensity indicator value is greater than the target carbon intensity indicator value, or if the predicted carbon intensity indicator value is less than or equal to the target carbon intensity indicator value but a difference between them does not exceed a certain threshold range, generates auxiliary decision suggestions for the target ship to improve the ship's carbon intensity indicator level;

the human-machine interaction module provides the target carbon intensity indicator value of the ship, the future voyage plan, and a selection confirmation command for user selection, and displays output results from the various modules.

Preferably, the data quality monitoring module further comprises a data delay alert sub-module and a voyage plan update alert sub-module; wherein the data delay alert sub-module extracts the latest data record from the historical voyage data upon the ship's departure from a destination port, and automatically checks at regular intervals whether a time difference between the departure time of the latest data record and the current time exceeds a preset time threshold, and triggers a historical voyage data delay alert if the threshold is exceeded;

and the voyage plan update alert sub-module automatically checks whether a time difference between an end time of the future voyage plan and the current time exceeds a preset time threshold, and triggers a future voyage plan update alert if the threshold is not exceeded or if no future voyage plan exists.

Preferably, in the level prediction module, outputting the predicted carbon intensity indicator values for the ship for each future calendar year and for each voyage within those future years comprises following steps:

S1: calculating, based on the remaining historical voyage data, a total fuel consumption and a total sailing distance for each leg within every voyage of the ship's current calendar year that has been executed according to the sequence of ports of call in the future voyage plan;

S2: obtaining port information from the historical voyage data when the ship departed from a destination port; calculating a total fuel consumption and a total sailing distance for the legs corresponding to the remaining, unexecuted sequence of ports of call after said port; and calculating the predicted carbon intensity indicator value for the ship for the current calendar year and for future years based on the total fuel consumption and the total sailing distance from both the executed and unexecuted legs;

S3: automatically determining whether an end time of the future voyage plan exceeds the last day of the current calendar year of the ship; if it exceeds, estimating the carbon intensity indicator value for the ship from the first leg of the unexecuted sequence of ports of call up to the leg encompassing the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following steps S1 and S2, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value;

S4: if the end time of the future voyage plan does not exceed the last day of the current calendar year of the ship, then copying the last voyage plan and appending it after the last voyage plan until

the end time of the future voyage plan exceeds the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following step S3, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value.

Preferably, in the level auxiliary decision module, generating auxiliary decision suggestions for a target ship to improve the ship's carbon intensity indicator level comprises:

S1': increasing a sailing time for remaining legs in the future voyage plan to improve the ship's carbon intensity indicator level;

S2': calculating a single-voyage carbon intensity indicator value for the ship based on other voyage plans, comparing it with the single-voyage carbon intensity indicator value of the target ship's current voyage, and suggesting a route change to another route if the value for the other voyage plan is less than that of the current voyage by a certain margin;

S3': incorporating energy saving ratios, calculated based on meteorological conditions for multiple types of energy-saving appendage devices, into the calculation of the single-voyage carbon intensity indicator value for the target ship's current route, and combining the energy saving ratios of various types of energy-saving appendage devices to improve the ship's carbon intensity indicator level;

S4': for a ship whose carbon intensity indicator level exceeds a preset level threshold, generating a ship energy efficiency management plan report for the ship, and allowing modification, saving, and downloading of the report via the human-machine interaction module.

Preferably, the system further comprises a data storage module and a user management module; wherein the human-machine interaction module is connected to the information acquisition module, the data quality monitoring module, the fuel consumption model building module, the level monitoring module, the level prediction module, and the level auxiliary decision module, respectively, via the data storage module; and the user management module is connected to the human-machine interaction module.

A ship carbon intensity indicator level auxiliary decision support method, comprising:

a step of information acquisition: collecting historical voyage data of the ship, as well as future voyage plan data and a target carbon intensity indicator value of the ship selected by a user via human-machine interaction;

a step of data quality monitoring: automatically determining whether sailing fuel consumption data,

berthing fuel consumption data, and sailing distance data in the historical voyage data are abnormal, and triggering a historical voyage data quality anomaly alert if an abnormality is determined; then automatically determining whether a sequence of ports of call in a current voyage of the ship is consistent with a sequence of ports of call in the future voyage plan, and triggering a non-compliance with voyage plan execution alert if they are inconsistent;

a step of fuel consumption model building: excluding the abnormal historical voyage data identified in the step of data quality monitoring, and building a sailing fuel consumption model and a berthing fuel consumption model based on the remaining historical voyage data;

a step of level monitoring: calculating a total sailing distance for a current calendar year of the ship and for each voyage within that year based on the remaining historical voyage data; calculating a total fuel consumption for the ship for that year and for each voyage within that year based on the sailing fuel consumption model and the berthing fuel consumption model; calculating a carbon intensity indicator value for the ship for that year and for each voyage within that year based on the total fuel consumption and the total sailing distance; and determining a carbon intensity indicator level based on the carbon intensity indicator value;

a step of level prediction: automatically determining whether the sequence of ports of call for the ship's current voyage is being executed according to the future voyage plan; outputting no prediction result if not; and outputting a predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those future years if so;

a step of level auxiliary decision: monitoring the predicted carbon intensity indicator values for each future year in real-time; automatically determining whether a predicted carbon intensity indicator value exceeds the target carbon intensity indicator value selected by the user; and generating auxiliary decision suggestions for the target ship to improve the ship's carbon intensity indicator level if the predicted value is greater than the target value, or if the predicted value is less than or equal to the target value but a difference between them does not exceed a certain threshold range;

a step of human-machine interaction: providing the target carbon intensity indicator value of the ship, the future voyage plan, and a selection confirmation command for user selection, and displaying output results from the various steps.

Preferably, in the step of data quality monitoring, the method further comprises: extracting a latest data record from the historical voyage data upon the ship's departure from a destination port;

automatically checking at regular intervals whether a time difference between the departure time of the latest data record and the current time exceeds a preset time threshold, and triggering a historical voyage data delay alert if the threshold is exceeded; and automatically checking whether a time difference between an end time of the future voyage plan and the current time exceeds a preset time threshold, and triggering a future voyage plan update alert if the threshold is not exceeded or if no future voyage plan exists.

Preferably, in the step of level prediction, outputting the predicted carbon intensity indicator values for the ship for each future calendar year and for each voyage within those future years comprises:

S1: calculating, based on the remaining historical voyage data, a total fuel consumption and a total sailing distance for each leg within every voyage of the ship's current calendar year that has been executed according to the sequence of ports of call in the future voyage plan;

S2: obtaining port information from the historical voyage data when the ship departed from a destination port; calculating a total fuel consumption and a total sailing distance for legs corresponding to the remaining, unexecuted sequence of ports of call after said port; and calculating the predicted carbon intensity indicator value for the ship for the current calendar year and for future years based on the total fuel consumption and the total sailing distance from both the executed and unexecuted legs;

S3: automatically determining whether an end time of the future voyage plan exceeds the last day of the current calendar year of the ship; if so, estimating the carbon intensity indicator value for the ship from the first leg of the unexecuted sequence of ports of call up to the leg encompassing the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following steps S1 and S2, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value;

S4: if the end time of the future voyage plan does not exceed the last day of the current calendar year of the ship, then copying the last voyage plan and appending it after the last voyage plan until the end time of the future voyage plan exceeds the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following step S3, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value.

Preferably, in the step of level auxiliary decision, generating auxiliary decision suggestions for a

target ship to improve its carbon intensity indicator level comprises:

S1': increasing a sailing time for remaining legs in the future voyage plan to improve the ship's carbon intensity indicator level;

S2': calculating a single-voyage carbon intensity indicator value for the ship based on other voyage plans, comparing it with the single-voyage carbon intensity indicator value of the target ship's current voyage, and suggesting a route change to another route if the value for the other voyage plan is less than that of the current voyage by a certain margin;

S3': incorporating energy saving ratios of different types, which are calculated based on meteorological conditions, into the calculation of the single-voyage carbon intensity indicator value for the target ship's current route, and improving the ship's carbon intensity indicator level by combining said different types of energy saving ratios;

S4': for a ship whose carbon intensity indicator level exceeds a preset level threshold, generating a ship energy efficiency management plan report for said ship, and enabling modification, saving, and downloading of the report within the human-machine interaction step.

Preferably, the step of level auxiliary decision further comprises: comparing the predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those years with the target carbon intensity indicator value selected by the user; wherein, if the predicted carbon intensity indicator value is greater than the target carbon intensity indicator value, an alarm message is triggered and an alarm prompt is generated.

The beneficial effects of the invention are as follows:

The present invention provides a ship Carbon Intensity Indicator (CII) level auxiliary decision support system. The system comprises an information acquisition module, a data quality monitoring module, a fuel consumption model building module, a level monitoring module, a level prediction module, a level auxiliary decision module, and a human-machine interaction module. These modules work together synergistically in the following manner: first, the system collects the ship's historical voyage data, as well as future voyage plan data and a target carbon intensity indicator value of the ship selected by a user via the human-machine interaction module, then determines whether the sailing fuel consumption data, berthing fuel consumption data, and sailing distance data in the historical voyage data are abnormal, and triggers a historical voyage data quality anomaly

alert if any abnormality is determined; it also determines whether the sequence of ports of call in the ship's current voyage is consistent with the sequence of ports of call in the future voyage plan, and triggers a non-compliance with voyage plan execution alert if they are inconsistent; subsequently, it excludes the abnormal historical voyage data identified by the data quality anomaly alert sub-module, and builds a sailing fuel consumption model and a berthing fuel consumption model based on the remaining historical voyage data. Next, it calculates the total sailing distance for the ship's current calendar year and for each voyage within that year based on the remaining historical voyage data; calculates the total fuel consumption for the ship for that year and for each voyage within that year based on the sailing fuel consumption model and the berthing fuel consumption model; calculates the carbon intensity indicator value for the ship for that year and for each voyage within that year based on the total fuel consumption and the total sailing distance; and determines the carbon intensity indicator level based on the carbon intensity indicator value. It then determines whether the sequence of ports of call for the ship's current voyage in the voyage plan anomaly alert sub-module is being executed according to the future voyage plan. If not, it outputs no prediction result; if so, it outputs the predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those future years. Finally, it monitors in real-time the predicted carbon intensity indicator values for each future year, and automatically determines whether a predicted carbon intensity indicator value exceeds the target carbon intensity indicator value selected by the user. If the predicted carbon intensity indicator value is greater than the target carbon intensity indicator value, or if the predicted carbon intensity indicator value is less than or equal to the target carbon intensity indicator value and the difference between them does not exceed a certain threshold range, it generates auxiliary decision suggestions for the target ship to improve the ship's carbon intensity indicator level. The invention can be used for real-time monitoring of container ship CII levels, providing early alarms of downgrade risks based on actual conditions, and offering guidance through auxiliary decision suggestions for level improvement. The system is very convenient and efficient to use, where users merely need to input search criteria and click buttons in the human-machine interaction module to retrieve and filter ship information that highly meets the relevant conditions. It can greatly enhance the monitoring and prediction capabilities of a ship's CII value, avoid the phenomenon of ship violations caused by exceeding the CII level limit, and facilitate the formulation of reasonable ship sailing plans in advance.

The present invention also relates to a ship carbon intensity indicator level auxiliary decision support method. This method corresponds to the ship carbon intensity indicator level auxiliary decision support system, and can be understood as an implementation method thereof. The method comprises the following steps: a step of information acquisition, a step of data quality monitoring, a step of fuel consumption model building, a step of level monitoring, a step of level prediction, a step of level auxiliary decision, and a step of human-machine interaction. By employing specific calculation and judgment methods, it enhances the monitoring and forecasting capabilities for the ship's CII value, helps prevent compliance violations due to exceeding the CII level limit, and facilitates the formulation of reasonable ship sailing plans in advance.

Description of the drawings

Figure 1 is a block diagram showing the structure of the ship carbon intensity indicator level auxiliary decision support system according to the present invention.

Figure 2 is a block diagram showing a preferred structure of the ship carbon intensity indicator level auxiliary decision support system according to the present invention.

Figure 3 is a flowchart illustrating the steps of the ship carbon intensity indicator level auxiliary decision support method according to the present invention.

Detailed description of embodiments

The present invention is described below in conjunction with the accompanying drawings.

The present invention relates to a ship Carbon Intensity Indicator (CII) level auxiliary decision support system. A structural block diagram of the system is shown in Figure 1. The system comprises an information acquisition module, a data quality monitoring module, a fuel consumption model building module, a level monitoring module, a level prediction module, a level auxiliary decision module, and a human-machine interaction module. The human-machine interaction module is connected, either directly or indirectly, to the information acquisition module, the data quality monitoring module, the fuel consumption model building module, the level monitoring module, the level prediction module, and the level auxiliary decision module. Furthermore, the information acquisition module, the data quality monitoring module, the fuel consumption model building module, the level monitoring module, the level prediction module, and the level auxiliary

decision module are connected sequentially. These modules interact synergistically. Through the use of specific calculation and judgment methods, the system is highly convenient and efficient to operate. Users can retrieve and filter ship information that closely matches relevant criteria by merely inputting search conditions and clicking buttons in the human-machine interaction module. This significantly enhances the capability to monitor and forecast the ship's Carbon Intensity Indicator (CII) value, helps prevent non-compliance incidents resulting from exceeding the CII level limit, and facilitates the proactive formulation of optimal ship sailing plans.

Specifically, as shown in the preferred structural diagram in Figure 2, this system comprises an information acquisition module, a data quality monitoring module, a fuel consumption model building module, a level monitoring module, a level prediction module, a level auxiliary decision module, a data storage module, a human-machine interaction module, and a user management module. In this embodiment, the human-machine interaction module is indirectly connected to the information acquisition module, the data quality monitoring module, the fuel consumption model building module, the level monitoring module, the level prediction module, and the level auxiliary decision module. This indirect connection is achieved through the data storage module; that is, the information acquisition module, data quality monitoring module, fuel consumption model building module, level monitoring module, level prediction module, and level auxiliary decision module are all connected to the human-machine interaction module via the data storage module. The data storage module is configured to store fundamental ship data, historical ship voyage data, future ship voyage plan data, route and port schedule data, as well as to store and provide key data generated by the various modules (such as the current CII value, predicted CII value, auxiliary decision suggestions, and the Ship Energy Efficiency Management Plan (SEEMP) report). The user management module is connected to the human-machine interaction module and is used to manage the permissions and functionalities of each user under the human-machine interaction module.

Herein, the information acquisition module is configured to acquire historical voyage data of the ship from the data storage module, and to collect future voyage plan data and a target carbon intensity indicator value (i.e., the CII value) of the ship selected by a user via the human-machine interaction module.

The data quality monitoring module comprises a data delay alert sub-module, a voyage plan update alert sub-module, a data quality anomaly alert sub-module, and a voyage plan anomaly alert

sub-module. Wherein, the data delay alert sub-module extracts the latest data record from the historical voyage data in the data storage module upon the ship's departure from a destination port, and then automatically checks at regular intervals (i.e., daily at 10:00) whether the time difference between the departure time of this latest record and the current time exceeds a preset time threshold, specifically, whether it exceeds 30 days, if the difference exceeds 30 days, it triggers a historical voyage data delay alert. The voyage plan update alert sub-module automatically checks whether the time difference between the end time of the future voyage plan in the data storage module and the current time exceeds the preset threshold (i.e., exceeds 30 days), if the time difference is less than or equal to 30 days, or if no future voyage plan exists, it triggers a future voyage plan update alert. The data quality anomaly alert sub-module automatically determines whether the sailing fuel consumption data, berthing fuel consumption data, and sailing distance data in the historical voyage data are abnormal, if any abnormality is determined, it triggers a historical voyage data quality anomaly alert. The voyage plan anomaly alert sub-module automatically determines whether the sequence of ports of call in the ship's current voyage is consistent with the sequence of ports of call in the future voyage plan, if they are inconsistent, it triggers a non-compliance with voyage plan execution alert.

The fuel consumption model building module is configured to perform regularity analysis on the sailing fuel consumption and berthing fuel consumption of the ship from the historical voyage data. Specifically, it first excludes the abnormal historical voyage data identified by the data quality anomaly alert sub-module. Then, based on the remaining historical voyage data, it builds a sailing fuel consumption model categorized by calendar year, fitting a sailing speed to hourly fuel consumption relationship formula, as shown in Equation (1) below:

$$F = ax^2 + bx + c \quad (1)$$

In the above equation, F is the hourly sailing fuel consumption, x is the sailing speed, and a , b , c are coefficients of the fitting formula.

Subsequently, based on the remaining historical voyage data, it builds a berthing fuel consumption model categorized by calendar year, fitting an hourly berthing fuel consumption formula, as shown in Equation (2) below:

$$T = ax^b + bx + c \quad (2)$$

In the above equation, T is the hourly berthing fuel consumption, x is the ship's draft, and a , b , c are coefficients of the fitting formula.

The level monitoring module calculates the total sailing distance for the ship's current calendar year and for each voyage within that year based on the aforementioned remaining historical voyage data. It then calculates the total fuel consumption for the ship for that year and for each voyage within that year, utilizing the sailing speed to hourly fuel consumption relationship formula derived from the sailing fuel consumption model and the hourly berthing fuel consumption formula derived from the berthing fuel consumption model. Based on the total fuel consumption and total sailing distance, it calculates the carbon intensity indicator value (i.e., the CII value) for the ship for that year and for each voyage within that year. The carbon intensity indicator level (i.e., the CII level) is then determined based on this CII value and in accordance with the specifications and requirements of the International Maritime Organization (IMO). The CII values and CII levels are displayed via the human-machine interaction module. This includes displaying the single-voyage CII value and CII level for each individual voyage, as well as the cumulative CII value and corresponding CII level after each successive voyage. For example, suppose Ship A completed three voyages in the 2022 calendar year: Voyage 001, Voyage 002, and Voyage 003. The level monitoring module calculates the total fuel consumption and total sailing distance from Voyage 001 through Voyage 003 to determine the annual CII value and CII level for 2022. It also sequentially calculates the total fuel consumption and sailing distance at the conclusion of Voyage 001 and then again at the conclusion of Voyage 002, obtaining the cumulative CII value and its corresponding CII level after each of these two points. Furthermore, it calculates the total fuel consumption and total sailing distance for each of the three voyages individually, resulting in three distinct single-voyage CII values and CII levels. All these calculation results are stored in the data storage module and are provided to the human-machine interaction module for display on the interface.

The level prediction module provides predicted CII values and predicted CII levels for future calendar years, as well as for individual voyages within those years, based on the future voyage plan. It first automatically determines whether the sequence of ports of call for the ship's current voyage, as monitored by the voyage plan anomaly alert sub-module, is being executed according to the future voyage plan. If not, no prediction result is output. If so, it outputs the predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those

future years. Herein, the prediction is performed once daily, and all prediction results are saved in the data storage module. Further, outputting the predicted carbon intensity indicator value specifically comprises following steps:

S1: Calculate, based on the remaining historical voyage data, the total fuel consumption and total sailing distance for each leg within every voyage of the ship's current calendar year that has been executed according to the sequence of ports of call in the future voyage plan (A leg is formed between two ports, and multiple legs constitute a voyage).

S2: Obtain the port information from the latest data record in the historical voyage data when the ship departed from a destination port. Calculate the total fuel consumption and total sailing distance for the legs corresponding to the remaining, unexecuted sequence of ports of call after said port up until the last day of the current calendar year (i.e., calculating the berthing fuel consumption, sailing fuel consumption, and sailing distance between respective ports). Then, calculate the predicted CII value and CII level for the ship for the current calendar year and for future years based on the total fuel consumption and total sailing distance from both the executed and unexecuted legs.

S3: Automatically determine whether the end time of the future voyage plan exceeds the last day of the ship's current calendar year (i.e., the year-crossing point). If it exceeds, identify the leg within the future voyage plan where the "departure time from the departure port < the year-crossing point" and the "arrival time at the destination port $\geq$ the year-crossing point". Estimate the ship's carbon intensity indicator value from the first leg of the unexecuted sequence of ports of call up to and including the leg containing the year-crossing point. Then, calculate the predicted carbon intensity indicator value (CII value) for the ship for that year by following steps S1 and S2, and determine the predicted carbon intensity indicator level (predicted CII level) based on this predicted value.

S4: If the end time of the future voyage plan does not exceed the last day of the ship's current calendar year, then copy the last voyage plan. The number of copies is determined by $(\text{Year-crossing point} - \text{End time of the future voyage plan}) / (\text{Total duration of the last voyage plan})$, rounded up to the nearest integer. Append these copies after the last planned voyage (using the end time of the last voyage plan as the departure time for the appended copies) until the end time of the future voyage plan exceeds the last day of the current calendar year. Then, calculate the predicted carbon intensity indicator value for the ship for that year by following step S3, and determine the carbon intensity indicator level based on this predicted carbon intensity indicator value.

The level auxiliary decision module monitors the predicted carbon intensity indicator values for each future year in real-time and automatically determines whether the predicted carbon intensity indicator value exceeds the target carbon intensity indicator value selected by the user. If the predicted carbon intensity indicator value is greater than the target carbon intensity indicator value, or if the predicted carbon intensity indicator value is less than or equal to the target carbon intensity indicator value but the difference between them falls within a certain threshold range, it generates auxiliary decision suggestions for the target ship to improve its carbon intensity indicator level.

Finally, the level auxiliary decision module compares the predicted carbon intensity indicator values for the ship for each future year and for each voyage within those years against the user-selected target carbon intensity indicator value. If any predicted carbon intensity indicator value is greater than the target carbon intensity indicator value, it triggers an alarm message and generates an alarm prompt.

The level auxiliary decision module is used to monitor the predicted carbon intensity indicator values for each future year in real-time and automatically determine whether the predicted carbon intensity indicator value exceeds the target carbon intensity indicator value selected by the user. If the predicted carbon intensity indicator value is greater than the target carbon intensity indicator value, or if the predicted carbon intensity indicator value is less than or equal to the target carbon intensity indicator value and the difference between them does not exceed a certain threshold range, that is, if the predicted carbon intensity indicator value is less than or equal to the target carbon intensity indicator value and the difference does not exceed 3% of the target value, then it generates auxiliary decision suggestions for the target ship to improve the ship's carbon intensity indicator level;

If an over-limit alarm is triggered for the target ship, it generates auxiliary decision suggestions, specifically:

- 1) Adjust the sailing time for the remaining legs in the future voyage plan by increasing the sailing duration, and estimate the adjusted predicted CII values for future years using the level prediction module. By increasing the sailing duration, the annual predicted CII value is made to be at least 10% better than the set target CII value, thereby improving the ship's carbon intensity indicator level.
- 2) Calculate the single-voyage carbon intensity indicator value for the ship based on other voyage plans in the data storage module, and compare it with the single-voyage carbon intensity indicator

value of the target ship's current voyage. If the single-voyage carbon intensity indicator value of another voyage plan is less than that of the target ship's current route by a certain margin, that is, if it is less than the current route's carbon intensity indicator value by more than 10%, then suggest changing to another route.

3) Incorporate the respective energy saving ratios of different types of energy-saving appendage devices, which are calculated based on meteorological conditions, into the calculation of the single-voyage CII value for the target ship's current route. The energy saving ratios of various types of energy-saving appendage devices can be combined in the calculation to provide installation suggestions for energy-saving appendage devices that can reduce the carbon intensity indicator value of the target ship's current route by more than 10%, thereby improving the ship's carbon intensity indicator level. For example, if the ship's CII value corresponds to a CII level that is 3% short of reaching Grade C or above, and the energy saving ratio of a first type of energy-saving appendage device is 1%, and that of a second type is 2%, then by adding the first type and the second type of energy-saving appendage devices, the ship's carbon intensity indicator value (CII value) can be made to reach Grade C or above.

4) For ships whose carbon intensity indicator level exceeds a preset level threshold, namely, for ships with a CII level of Grade D or E, generate a Ship Energy Efficiency Management Plan (SEEMP) report for that ship, and allow it to be modified, saved, and downloaded via the human-machine interaction module.

The human-machine interaction module provides the target carbon intensity indicator value of the ship, the future voyage plan, and a selection confirmation command for user selection, and displays output results from the various modules. Specifically, the human-machine interaction module can display real-time CII values and CII levels for each ship, voyage-based and annual CII predictions, and monitoring information provided by the data quality monitoring module. Furthermore, the user can set the target CII value and CII level for each ship, input future voyage plans, view auxiliary decision information, and modify, save, and download the SEEMP report via the human-machine interaction interface.

The present invention also relates to a ship carbon intensity indicator level auxiliary decision support method. This method corresponds to the ship carbon intensity indicator level auxiliary decision support system and can be understood as an implementation method thereof. As shown in

Figure 3, the method comprises the following steps: a step of information acquisition, a step of data quality monitoring, a step of fuel consumption model building, a step of level monitoring, a step of level prediction, a step of level auxiliary decision, and a step of human-machine interaction.

A step of information acquisition: collecting historical voyage data of the ship, as well as future voyage plan data and a target carbon intensity indicator value of the ship selected by a user via human-machine interaction;

a step of data quality monitoring: automatically determining whether sailing fuel consumption data, berthing fuel consumption data, and sailing distance data in the historical voyage data are abnormal, and triggering a historical voyage data quality anomaly alert if an abnormality is determined; then automatically determining whether a sequence of ports of call in a current voyage of the ship is consistent with a sequence of ports of call in the future voyage plan, and triggering a non-compliance with voyage plan execution alert if they are inconsistent;

a step of fuel consumption model building: excluding the abnormal historical voyage data identified in the step of data quality monitoring, and building a sailing fuel consumption model and a berthing fuel consumption model based on the remaining historical voyage data;

a step of level monitoring: calculating a total sailing distance for a current calendar year of the ship and for each voyage within that year based on the remaining historical voyage data; calculating a total fuel consumption for the ship for that year and for each voyage within that year based on the sailing fuel consumption model and the berthing fuel consumption model; calculating a carbon intensity indicator value for the ship for that year and for each voyage within that year based on the total fuel consumption and the total sailing distance; and determining a carbon intensity indicator level based on the carbon intensity indicator value;

a step of level prediction: automatically determining whether the sequence of ports of call for the ship's current voyage is being executed according to the future voyage plan; outputting no prediction result if not; and outputting a predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those future years if so;

a step of level auxiliary decision: monitoring the predicted carbon intensity indicator values for each future year in real-time; automatically determining whether a predicted carbon intensity indicator value exceeds the target carbon intensity indicator value selected by the user; and generating auxiliary decision suggestions for the target ship to improve the ship's carbon intensity indicator

level if the predicted value is greater than the target value, or if the predicted value is less than or equal to the target value but a difference between them does not exceed a certain threshold range; a step of human-machine interaction: providing the target carbon intensity indicator value of the ship, the future voyage plan, and a selection confirmation command for user selection, and displaying output results from the various steps.

Preferably, in the step of data quality monitoring, the method further comprises: extracting a latest data record from the historical voyage data upon the ship's departure from a destination port; automatically checking at regular intervals whether a time difference between the departure time of the latest data record and the current time exceeds a preset time threshold, and triggering a historical voyage data delay alert if the threshold is exceeded; and automatically checking whether a time difference between an end time of the future voyage plan and the current time exceeds a preset time threshold, and triggering a future voyage plan update alert if the threshold is not exceeded or if no future voyage plan exists.

Preferably, in the step of level prediction, outputting the predicted carbon intensity indicator values for the ship for each future calendar year and for each voyage within those future years comprises:

S1: calculating, based on the remaining historical voyage data, a total fuel consumption and a total sailing distance for each leg within every voyage of the ship's current calendar year that has been executed according to the sequence of ports of call in the future voyage plan;

S2: obtaining port information from the historical voyage data when the ship departed from a destination port; calculating a total fuel consumption and a total sailing distance for legs corresponding to the remaining, unexecuted sequence of ports of call after said port; and calculating the predicted carbon intensity indicator value for the ship for the current calendar year and for future years based on the total fuel consumption and the total sailing distance from both the executed and unexecuted legs;

S3: automatically determining whether an end time of the future voyage plan exceeds the last day of the current calendar year of the ship; if so, estimating the carbon intensity indicator value for the ship from the first leg of the unexecuted sequence of ports of call up to the leg encompassing the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following steps S1 and S2, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value;

S4: if the end time of the future voyage plan does not exceed the last day of the current calendar year of the ship, then copying the last voyage plan and appending it after the last voyage plan until the end time of the future voyage plan exceeds the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following step S3, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value.

Preferably, in the step of level auxiliary decision, generating auxiliary decision suggestions for a target ship to improve its carbon intensity indicator level comprises:

S1': increasing a sailing time for remaining legs in the future voyage plan to improve the ship's carbon intensity indicator level;

S2': calculating a single-voyage carbon intensity indicator value for the ship based on other voyage plans, comparing it with the single-voyage carbon intensity indicator value of the target ship's current voyage, and suggesting a route change to another route if the value for the other voyage plan is less than that of the current voyage by a certain margin;

S3': incorporating energy saving ratios of different types, which are calculated based on meteorological conditions, into the calculation of the single-voyage carbon intensity indicator value for the target ship's current route, and improving the ship's carbon intensity indicator level by combining said different types of energy saving ratios;

S4': for a ship whose carbon intensity indicator level exceeds a preset level threshold, generating a ship energy efficiency management plan report for said ship, and enabling modification, saving, and downloading of the report within the human-machine interaction step.

Preferably, the step of level auxiliary decision further comprises: comparing the predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those years with the target carbon intensity indicator value selected by the user; wherein, if the predicted carbon intensity indicator value is greater than the target carbon intensity indicator value, an alarm message is triggered and an alarm prompt is generated.

The present invention provides an objective and scientific ship carbon intensity indicator (CII) level auxiliary decision support system and method. By employing specific calculation and assessment methods, it can be used for real-time monitoring of container ship CII level, providing early alarms of downgrade risks based on actual conditions, and offering guided decision support for level

improvement. It enhances the capability to monitor and forecast a ship's CII value, helps prevent non-compliance incidents resulting from exceeding CII level limits, and facilitates the proactive formulation of reasonable ship sailing plans.

It should be pointed out that the foregoing specific embodiments are provided to enable those skilled in the art to more fully understand the present invention, but in no way limit the present invention. Therefore, although the present invention has been described in detail with reference to the accompanying drawings and embodiments, those skilled in the art should understand that modifications or equivalent substitutions can still be made to the present invention. In summary, any technical solutions and improvements thereof that do not depart from the spirit and scope of the present invention shall fall within the protection scope of the present invention patent.

Claims

1. A ship carbon intensity indicator level auxiliary decision support system, comprising:
an information acquisition module, a data quality monitoring module, a fuel consumption model building module, a level monitoring module, a level prediction module, a level auxiliary decision module, and a human-machine interaction module; wherein the human-machine interaction module is respectively connected to the information acquisition module, the data quality monitoring module, the fuel consumption model building module, the level monitoring module, the level prediction module, and the level auxiliary decision module; and the information acquisition module, the data quality monitoring module, the fuel consumption model building module, the level monitoring module, the level prediction module, and the level auxiliary decision module are connected in sequence;
the information acquisition module collects historical voyage data of the ship, as well as future voyage plan data and a target carbon intensity indicator value of the ship selected by a user via the human-machine interaction module;
the data quality monitoring module comprises a data quality anomaly alert sub-module and a voyage plan anomaly alert sub-module, wherein the data quality anomaly alert sub-module automatically determines whether sailing fuel consumption data, berthing fuel consumption data, and sailing distance data in the historical voyage data are abnormal, and triggers a historical voyage data quality anomaly alert if abnormality is determined; and the voyage plan anomaly alert sub-module automatically determines whether a sequence of ports of call in a current voyage of the ship is consistent with a sequence of ports of call in the future voyage plan, and triggers a non-compliance with voyage plan execution alert if they are inconsistent;
the fuel consumption model building module excludes the abnormal historical voyage data determined by the data quality anomaly alert sub-module, and builds a sailing fuel consumption model and a berthing fuel consumption model based on the remaining historical voyage data;
the level monitoring module calculates a total sailing distance for a current calendar year of the ship and for each voyage within that year based on the remaining historical voyage data, calculates a total fuel consumption for the ship for that year and for each voyage within that year based on the

sailing fuel consumption model and the berthing fuel consumption model, calculates a carbon intensity indicator value for the ship for that year and for each voyage within that year based on the total fuel consumption and the total sailing distance, and determines a carbon intensity indicator level based on the carbon intensity indicator value;

the level prediction module automatically determines whether the sequence of ports of call for the ship's current voyage, as monitored by the voyage plan anomaly alert sub-module, is being executed according to the future voyage plan; if not, no prediction result is output; if so, it outputs a predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those future years;

the level auxiliary decision module monitors the predicted carbon intensity indicator values for each future year in real-time, and automatically determines whether the predicted carbon intensity indicator value exceeds a target carbon intensity indicator value selected by the user, and if the predicted carbon intensity indicator value is greater than the target carbon intensity indicator value, or if the predicted carbon intensity indicator value is less than or equal to the target carbon intensity indicator value but a difference between them does not exceed a certain threshold range, generates auxiliary decision suggestions for the target ship to improve the ship's carbon intensity indicator level;

the human-machine interaction module provides the target carbon intensity indicator value of the ship, the future voyage plan, and a selection confirmation command for user selection, and displays output results from the various modules.

2. The ship carbon intensity indicator level auxiliary decision support system according to claim 1, wherein the data quality monitoring module further comprises a data delay alert sub-module and a voyage plan update alert sub-module; wherein the data delay alert sub-module extracts the latest data record from the historical voyage data upon the ship's departure from a destination port, and automatically checks at regular intervals whether a time difference between the departure time of the latest data record and the current time exceeds a preset time threshold, and triggers a historical voyage data delay alert if the preset time threshold is exceeded;

and the voyage plan update alert sub-module automatically checks whether a time difference between an end time of the future voyage plan and the current time exceeds a preset time threshold,

and triggers a future voyage plan update alert if the preset time threshold is not exceeded or if no future voyage plan exists.

3. The ship carbon intensity indicator level auxiliary decision support system according to claim 1, wherein, in the level prediction module, outputting the predicted carbon intensity indicator values for the ship for each future calendar year and for each voyage within those future years comprises following steps:

S1: calculating, based on the remaining historical voyage data, a total fuel consumption and a total sailing distance for each leg within every voyage of the ship's current calendar year that has been executed according to the sequence of ports of call in the future voyage plan;

S2: obtaining port information from the historical voyage data when the ship departed from a destination port; calculating a total fuel consumption and a total sailing distance for the legs corresponding to the remaining, unexecuted sequence of ports of call after said port; and calculating the predicted carbon intensity indicator value for the ship for the current calendar year and for future years based on the total fuel consumption and the total sailing distance from both the executed and unexecuted legs;

S3: automatically determining whether an end time of the future voyage plan exceeds the last day of the current calendar year of the ship; if it exceeds, estimating the carbon intensity indicator value for the ship from the first leg of the unexecuted sequence of ports of call up to the leg encompassing the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following steps S1 and S2, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value;

S4: if the end time of the future voyage plan does not exceed the last day of the current calendar year of the ship, then copying the last voyage plan and appending it after the last voyage plan until the end time of the future voyage plan exceeds the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following step S3, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value.

4. The ship carbon intensity indicator level auxiliary decision support system according to any one

of claims 1 to 3, wherein, in the level auxiliary decision module, generating auxiliary decision suggestions for a target ship to improve the ship's carbon intensity indicator level comprises:

S1': increasing a sailing time for remaining legs in the future voyage plan to improve the ship's carbon intensity indicator level;

S2': calculating a single-voyage carbon intensity indicator value for the ship based on other voyage plans, comparing it with the single-voyage carbon intensity indicator value of the target ship's current voyage, and suggesting a route change to another route if the value for the other voyage plan is less than that of the current voyage by a certain margin;

S3': incorporating energy saving ratios, calculated based on meteorological conditions for multiple types of energy-saving appendage devices, into the calculation of the single-voyage carbon intensity indicator value for the target ship's current route, and combining the energy saving ratios of various types of energy-saving appendage devices to improve the ship's carbon intensity indicator level;

S4': for a ship whose carbon intensity indicator level exceeds a preset level threshold, generating a ship energy efficiency management plan report for the ship, and allowing modification, saving, and downloading of the report via the human-machine interaction module.

5. The ship carbon intensity indicator level auxiliary decision support system according to any one of claims 1 to 3, further comprising a data storage module and a user management module; wherein the human-machine interaction module is connected to the information acquisition module, the data quality monitoring module, the fuel consumption model building module, the level monitoring module, the level prediction module, and the level auxiliary decision module, respectively, via the data storage module; and the user management module is connected to the human-machine interaction module.

6. A ship carbon intensity indicator level auxiliary decision support method, comprising:

a step of information acquisition: collecting historical voyage data of the ship, as well as future voyage plan data and a target carbon intensity indicator value of the ship selected by a user via human-machine interaction;

a step of data quality monitoring: automatically determining whether sailing fuel consumption data, berthing fuel consumption data, and sailing distance data in the historical voyage data are abnormal,

and triggering a historical voyage data quality anomaly alert if an abnormality is determined; then automatically determining whether a sequence of ports of call in a current voyage of the ship is consistent with a sequence of ports of call in the future voyage plan, and triggering a non-compliance with voyage plan execution alert if they are inconsistent;

a step of fuel consumption model building: excluding the abnormal historical voyage data identified in the step of data quality monitoring, and building a sailing fuel consumption model and a berthing fuel consumption model based on the remaining historical voyage data;

a step of level monitoring: calculating a total sailing distance for a current calendar year of the ship and for each voyage within that year based on the remaining historical voyage data; calculating a total fuel consumption for the ship for that year and for each voyage within that year based on the sailing fuel consumption model and the berthing fuel consumption model; calculating a carbon intensity indicator value for the ship for that year and for each voyage within that year based on the total fuel consumption and the total sailing distance; and determining a carbon intensity indicator level based on the carbon intensity indicator value;

a step of level prediction: automatically determining whether the sequence of ports of call for the ship's current voyage is being executed according to the future voyage plan; outputting no prediction result if not; and outputting a predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those future years if so;

a step of level auxiliary decision: monitoring the predicted carbon intensity indicator values for each future year in real-time; automatically determining whether a predicted carbon intensity indicator value exceeds the target carbon intensity indicator value selected by the user; and generating auxiliary decision suggestions for the target ship to improve the ship's carbon intensity indicator level if the predicted value is greater than the target value, or if the predicted value is less than or equal to the target value but a difference between them does not exceed a certain threshold range;

a step of human-machine interaction: providing the target carbon intensity indicator value of the ship, the future voyage plan, and a selection confirmation command for user selection, and displaying output results from the various steps.

7. The ship carbon intensity indicator level auxiliary decision support method according to claim 6, wherein the step of data quality monitoring further comprises: extracting a latest data record from

the historical voyage data upon the ship's departure from a destination port; automatically checking at regular intervals whether a time difference between the departure time of the latest data record and the current time exceeds a preset time threshold, and triggering a historical voyage data delay alert if the threshold is exceeded; and automatically checking whether a time difference between an end time of the future voyage plan and the current time exceeds a preset time threshold, and triggering a future voyage plan update alert if the threshold is not exceeded or if no future voyage plan exists.

8. The ship carbon intensity indicator level auxiliary decision support method according to claim 6, wherein, in the step of level prediction, outputting the predicted carbon intensity indicator values for the ship for each future calendar year and for each voyage within those future years comprises:

S1: calculating, based on the remaining historical voyage data, a total fuel consumption and a total sailing distance for each leg within every voyage of the ship's current calendar year that has been executed according to the sequence of ports of call in the future voyage plan;

S2: obtaining port information from the historical voyage data when the ship departed from a destination port; calculating a total fuel consumption and a total sailing distance for legs corresponding to the remaining, unexecuted sequence of ports of call after said port; and calculating the predicted carbon intensity indicator value for the ship for the current calendar year and for future years based on the total fuel consumption and the total sailing distance from both the executed and unexecuted legs;

S3: automatically determining whether an end time of the future voyage plan exceeds the last day of the current calendar year of the ship; if so, estimating the carbon intensity indicator value for the ship from the first leg of the unexecuted sequence of ports of call up to the leg encompassing the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following steps S1 and S2, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value;

S4: if the end time of the future voyage plan does not exceed the last day of the current calendar year of the ship, then copying the last voyage plan and appending it after the last voyage plan until the end time of the future voyage plan exceeds the last day of the current calendar year; then calculating the predicted carbon intensity indicator value for the ship for that year by following step

S3, and determining the carbon intensity indicator level based on the predicted carbon intensity indicator value.

9. The ship carbon intensity indicator level auxiliary decision support method according to claim 6, wherein, in the step of level auxiliary decision, generating auxiliary decision suggestions for a target ship to improve its carbon intensity indicator level comprises:

S1': increasing a sailing time for remaining legs in the future voyage plan to improve the ship's carbon intensity indicator level;

S2': calculating a single-voyage carbon intensity indicator value for the ship based on other voyage plans, comparing it with the single-voyage carbon intensity indicator value of the target ship's current voyage, and suggesting a route change to another route if the value for the other voyage plan is less than that of the current voyage by a certain margin;

S3': incorporating energy saving ratios of different types, which are calculated based on meteorological conditions, into the calculation of the single-voyage carbon intensity indicator value for the target ship's current route, and improving the ship's carbon intensity indicator level by combining said different types of energy saving ratios;

S4': for a ship whose carbon intensity indicator level exceeds a preset level threshold, generating a ship energy efficiency management plan report for said ship, and enabling modification, saving, and downloading of the report within the human-machine interaction step.

10. The ship carbon intensity indicator level auxiliary decision support method according to any one of claims 6 to 9, wherein the step of level auxiliary decision further comprises: comparing the predicted carbon intensity indicator value for the ship for each future calendar year and for each voyage within those years with the target carbon intensity indicator value selected by the user; wherein, if the predicted carbon intensity indicator value is greater than the target carbon intensity indicator value, an alarm message is triggered and an alarm prompt is generated.