SOPass Ship Operation Support System that Optimizes the Economic and Environmental Performance of LNG Carriers

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The demand for natural gas, which is environmentally friendly, is increasing because of the global trend toward carbon neutrality. Also, a greenhouse gas emissions evaluation system has been put into effect in the international maritime industry, and LNG carriers, which play a key role in the marine transportation of natural gas, are required to achieve a good balance between boosting transportation efficiency and evaluating environmental impact. SOPass, which we developed, allows us to respond to these challenges by proposing optimal ship operations based on model calculations and evaluating environmental impact with operational data analysis (CII).

Introduction

Demand for natural gas, which is the most environmentally friendly fossil fuel, is increasing because of the global trend toward carbon neutrality. As LNG carriers are used for long-distance natural gas transportation, such as transportation between continents, because pipeline building is not economical, there is high demand for more efficient long-distance marine transportation of LNG. In particular, a supply and demand imbalance has recently been caused by delays in new LNG export projects, including those related to shale gas in the U.S., and increased demand for LNG in Europe associated with the stoppage of pipeline gas supply due to the Russian invasion of Ukraine. Soaring LNG prices have further increased demand for more efficient natural gas transportation by LNG carriers.

In addition, in the international maritime industry,regulations on a greenhouse gas (GHG) emissions have been implemented. With regard to LNG carrier operations, there is now demand for a ship operation management support system to both boost transportation efficiency and reduce the quantity of environmentally unfriendly substances, evaluating the results of these measures as indices.

1 Background and history

Around the year 2000, we developed and began to provide a ship operation support system that makes use of communication between ships and land. First, we developed a system that analyzes the performance of the main engine and that monitors the machinery part in general cargo ships on land. We then developed and provided a wide range of ship operation support systems, including a vessel performance analysis system for LNG carriers and an optimal route calculation (weather routing) system for general cargo ships.

In 2016, we released a ship operation management support system for LNG carriers, SOPass (Ship Operation and Performance analysis system), and we started to provide service in 2017, anticipating needs for efficiency improvement in marine transportation of LNG.

SOPass was developed to support charterers who are involved in the operation management of LNG carriers on land as key players in natural gas transactions. SOPass is equipped with various applications that can be used seamlessly from before, during, and after voyages. By providing a future prediction function and an evaluation function in addition to a function to check the statuses of ships in real time, we aimed to enable the service to

† A ship operation management support system that merges real data from a ship with engineering insights from the shipyard to analyze data and to predict the future in order to support efficient ship operation.

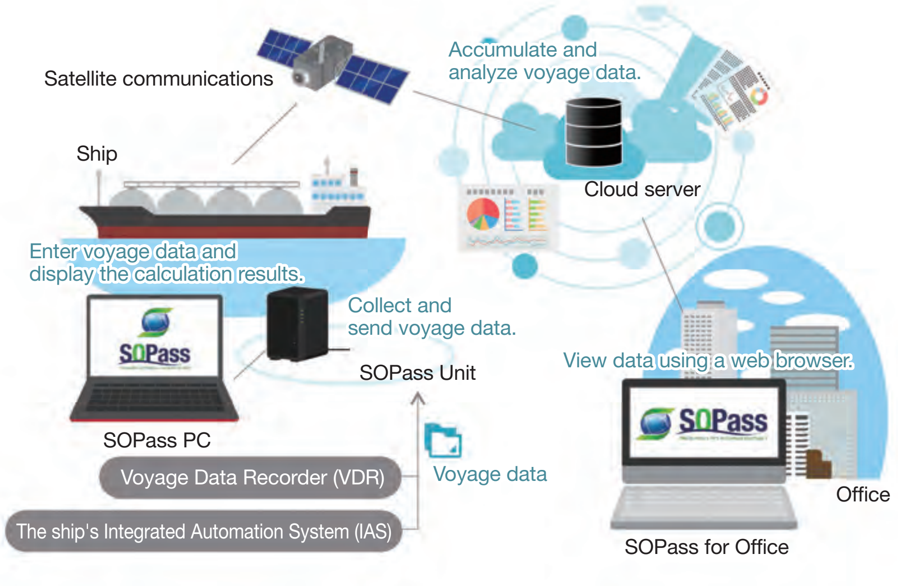

Fig. 1 System configuration and data flow schematic

identify and examine future actions for ship operations without requiring advanced expertise and many years of experience.

Fig. 1 shows the system configuration and data flow schematic of SOPass. SOPass collects ship operation data in a datacenter on land via satellite communications, analyzes the data according to the purpose of application, and computes a model simulation to predict future voyages. The SOPass user can view the operation status and analysis results of the main ship via a web browser at any time, anywhere.

2 Challenges that SOPass can solve

(1) Improvement of the transportation efficiency of LNG carriers

Some challenges are specific to laden and ballast voyages.

One challenge for laden voyages is to productively use NBOG (Natural Boil Off Gas) as propulsion energy or electricity on board. NBOG is a gas generated from LNG in the cargo tank when it partly vaporizes due to heat input from outside. During a voyage, the inner pressure in the cargo tank must be properly controlled by extracting this gas to decrease the pressure in the cargo tank, which rises due to NBOG. The extracted NBOG is used as fuel for the main engine. If the ship is not equipped with a reliquefaction system, extra NBOG that cannot be consumed due to the main engine's output status is wastefully burned in the combustion unit. The operation plan with the highest transportation efficiency consists of main engine output that is maintained so as to balance the amount of NBOG extracted from the cargo tank with the main engine's NBOG consumption, the vessel speed obtained based on the output of the main engine and the route, and the ship operations obtained by considering these in a composite way.

One challenge for ballast voyages is to determine the exact amount of LNG (amount of heel) that should be left in the cargo tank to cool the cargo tank and to be used as fuel for propulsion and power generation. To maximize the LNG discharge amount at the end of a laden voyage, it is desirable to reduce the amount of heel for the next ballast voyage as much as possible. However, because the necessary amount of heel during a ballast voyage differs by cargo tank type, the number of voyage days, and fuel consumption for the route, these factors must be sufficiently considered when determining the exact amount of heel. Another challenge is how to productively use the SBOG (Spray Boil Off Gas) generated when LNG sprayed in the cargo tank to cool it vaporizes as propulsion energy and electricity on board.

To address these challenges, we must make it possible to propose optimal plant operations and routes for LNG carriers, thus constraining the loss of LNG, their cargo.

(2) Environmental impact evaluation of LNG carriers

In the international maritime industry, which has implemented measures to reduce GHG emissions, the evaluation of ships' GHG emissions is an urgent challenge. Since the international evaluation system for the environmental impact during ship operation started in 2023, in the industry's efforts toward carbon neutrality, visualization of ships' actual fuel efficiency for evaluation is gathering much attention.

The CII (Carbon Intensity Indicator), which serves as an evaluation index for LNG carriers, can be expressed by the following equation.

$$CII = \frac{CO_2 \text{ emissions [g]}}{\text{Deadweight (DWT) [MT]} \times \text{Actual navigation distance [NM]}}$$

MT：Metric Ton
NM：Nautical Mile

A carbon intensity rating of A to E is determined according to the attained CII. If a ship has a low carbon intensity rating, the shipowner must create an improvement plan for the ship and obtain approval from the authority. In addition, because the International Maritime Organization (IMO), which established this system, encourages parties in the maritime industry, including the main supervising agency and port authorities, to reward ships that have high carbon intensity ratings, it has become important in relation to ship operations to monitor the attained CIIs and to improve carbon intensity ratings.

In addition, companies in the international maritime industry have established the Sea Cargo Charter for cargo owners and maritime companies to evaluate and announce how well operating ships are meeting the IMO's GHG emissions reduction goal, and they have established the Poseidon Principles for financial institutions' ship loan portfolios. Therefore, evaluation of GHG emissions from ship operations can be considered a maritime-industry-wide challenge.

3 Problem-solving processes using SOPass

(1) Efforts to boost the transportation efficiency of LNG carriers

We have developed BOG-Navigation, which is a function that contributes to improving the efficiency of marine transportation of LNG, by combining the optimal route calculation technology and the operation data analysis technology we have created through past system development, operational insights from the construction of LNG carriers, our thermodynamic evaluation technology, and more.

(i) Prediction of ship motion and LNG state

SOPass can predict the amount of increase in the ship resistance and the swing of the ship as a result of changes in marine climate conditions based on the vessel performance model constructed using design data during ship construction. As shown in **Fig. 2**, the system can predict the amount of increase in the resistance according to the cycle and direction of waves to which the ship is subjected at a given vessel speed, using the vessel

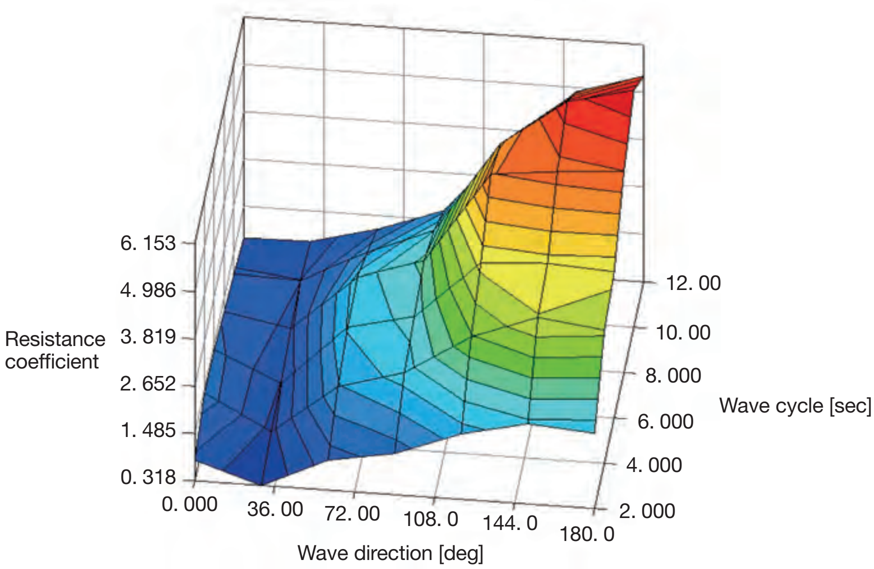

Fig. 2 Amount of increase in resistance in irregular waves at a certain vessel speed

performance model to predict the amount of increase in the resistance due to waves. In addition, the system can calculate the shaft output, number of propeller revolutions, vessel speed, and fuel consumption required for ship propulsion by predicting the wind resistance against the ship, wave-making resistance, viscosity resistance, and other factors. It can also predict the motion of the ship in waves and wind, such as rolling and pitching.

Furthermore, the system can predict the states of the cargo tank as well as the liquid and vapor inside the cargo tank based on the cargo tank heat transfer model constructed with consideration given to structural factors such as the hull, tank, and piping. Moreover, it can predict the pressure in the cargo tank and the amount, temperature, and composition of LNG, which changes from hour to hour in response to the ambient air temperature, sea temperature, and heat intrusion, such as solar radiation. **Fig. 3** shows the calculation result of the solar radiation impact using a heat transfer model constructed using the design data of an LNG carrier that we built. The amount of NBOG and SBOG generated in the cargo tank as well as the equator temperature for Moss tanks and the LNG temperature at each liquid level for membrane tanks can also be predicted.

By making it possible to predict the ship motion and LNG state through model simulation, the statuses of LNG carriers during voyage can be predicted.

(ii) Proposal of ship operations for higher transportation efficiency

We have developed the BOG-Navigation function to propose ship operations that improve the transportation efficiency of LNG carriers by combining the LNG carrier plant operation technology we have accumulated as a shipyard, prediction data on the statuses of LNG carriers through the model simulation described in section (i), and weather routing technology.

BOG-Navigation predicts elements such as the amount of generated NBOG, changes in tank pressure, and changes in LNG composition (aging) during laden voyages using marine weather forecast data as an input to calculate the hourly amount of energy that can be used as fuel for propulsion during a voyage. This function has succeeded in boosting the transportation efficiency of each voyage by presenting plant operations and a route by which the available energy is not wasted. Because BOG-Navigation can predict ship motion according to marine climate conditions in addition to the LNG state, the user can set upper limit values for the wave height as well as rolling and pitching angles during the voyage to limit operations and utilize information on the safest, most fuel-efficient route and prediction information on the ship operation status for the voyage. The user on land can share this voyage prediction information with the main ship by web browser. In addition, BOG-Navigation automatically calculates a plan from the current position of the main ship to the destination port and provides it to the user on land and the main ship daily as shown in **Fig. 4**. The user on land can share voyage prediction information that is continuously calculated using the latest marine weather forecast data with the main ship.

In addition, the amount of heel required for ballast voyages can be estimated based on the optimal cooling spray pattern as well as the cooling spray amount and fuel consumption required for the voyage predicted using the model described in section (i). The LNG discharge amount can be maximized by predicting and presenting the minimum necessary amount of heel for the next ballast voyage when a laden voyage is completed.

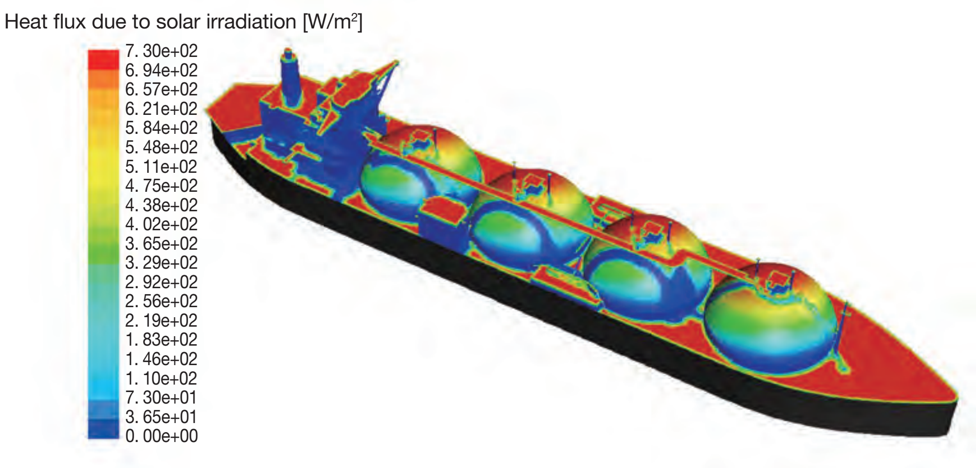

Fig. 3 Solar radiation impact calculation by heat transfer model

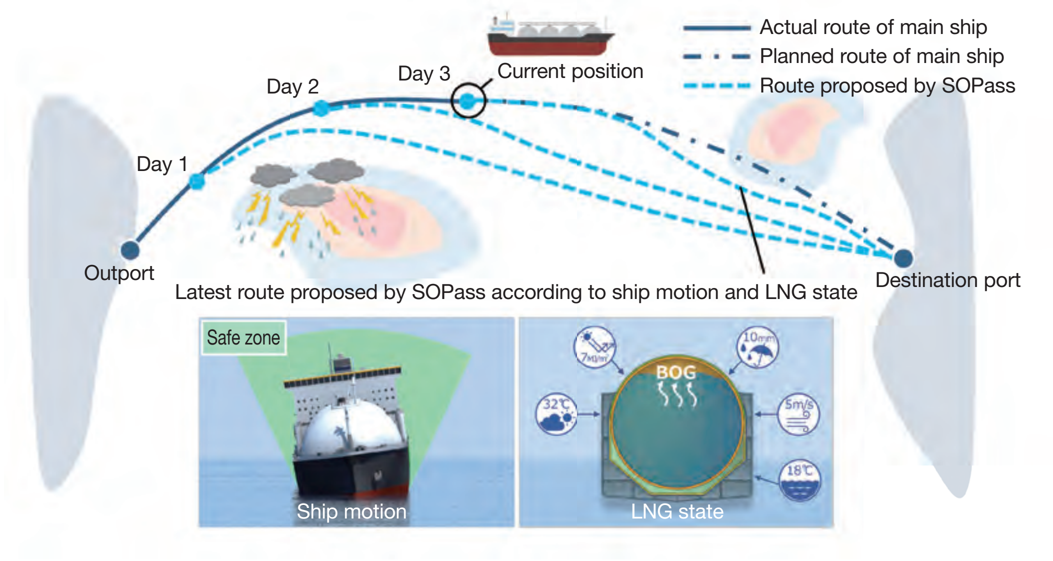

Fig. 4 Outline of periodic calculation by BOG-Navigation

(2) Efforts to evaluate the environmental impact of LNG carriers

Under the CII regulation, to determine the carbon intensity rating, attained CIIs calculated based on the actual operation data for one year are evaluated. Actual operation data—such as the type of fuel used by the ship, fuel consumption, and navigation distance—is required to calculate the attained CIIs. For SOPass, we developed CII Evaluation to estimate ships' CO_2 emissions and the trend in attained CIIs from such actual operation data in order to provide CII evaluation information that is continuously calculated from the latest actual operation data.

On the CII evaluation information display screen shown in **Fig. 5**, the attained CII (①) and CO_2 emissions (②) of each voyage can be displayed in addition to these values per annum, which is the CII regulation's evaluation period for evaluating the environmental impact of each voyage. The screen also has a section (③) to check to what extent the navigation distance and CO_2 emissions must be changed to improve the carbon intensity rating. This section can be used to examine the operation method in order to improve the rating.

In addition, there is a screen that displays the trend graph for CO_2 emissions and attained CIIs at 30-minute

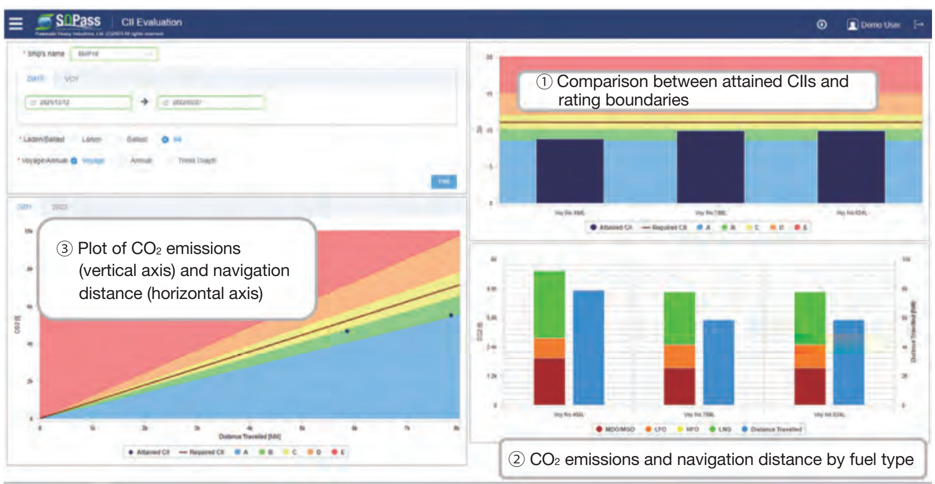

Fig. 5 Representation of CII evaluation information for each voyage

intervals. This graph can be checked against the trend graphs of marine climate data and actual past operations provided by SOPass to analyze why the attained CII fell during a voyage and to improve the operation method.

Conclusion

BOG-Navigation, which supports future voyage planning, is a proprietary function we have developed by leveraging our strengths as a shipyard and advanced thermodynamic evaluation technology. We will work on future prediction using machine learning to achieve highly practical operation support in order to predict the future operation statuses of ships more accurately.

We are considering leveraging SOPass to boost the transportation efficiency of liquefied hydrogen carriers in transporting hydrogen, which we are examining as a source of zero emissions energy, by developing this technology going forward.

In addition, regarding CII Evaluation, which provides only evaluation information for actual values at present, we aim to release a function to predict future CII evaluation values based on actual operation data and future voyage schedules at an early date.

We will continue to carry out aggressive development by combining our technologies to extend the functionality of SOPass and contribute to further efficiency improvements in marine transportation and GHG emissions reductions across the international maritime industry.

Naoko Morita
IoT Business Promotion Department,
Engineering Group,
Ship & Offshore Structure Business Division,
Energy Solution & Marine Engineering Company

Ai Yamazoe
IoT Business Promotion Department,
Engineering Group,
Ship & Offshore Structure Business Division,
Energy Solution & Marine Engineering Company

Hidekazu Iwasaki
Technology Group, Hydrogen Strategy Division

Hirotaka Takata
Energy System Research Department,
Technical Institute,
Corporate Technology Division

Nobuhiro Shimmura
Energy System Research Department,
Technical Institute,
Corporate Technology Division