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Evaluation of ship performance in international maritime transportation using an onboard measurement system - in case of a bulk carrier in international voyages

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ABSTRACT

The present global society has made the development of a safe and efficient maritime transportation system more imperative than ever before. Of particular impetus is the steep rise in the price of crude oil, which has required shipping companies to minimize the fuel consumption of their ships. Moreover, the emission of carbon dioxide has been restricted by the EEDI (Energy Efficiency Design Index) issued by the IMO (International Maritime Organization). Weather routing services have become more important to shipping companies. However, there are accuracy deficiencies in the numerical models employed by such services for purposes such as weather forecast and the ship speed loss phenomenon. Moreover, the development of weather routing models has been hampered by insufficient accumulation of continuous data on ship motions, and the navigation, engine, and weather parameters. The data used for this study was collected over one year from a 20,000 DWT class bulk carrier on worldwide voyages. Some new relationships regarding ship motions, speed loss, and wave conditions were developed, which were verified by experimental data and numerical simulations of the frequency response of the ship motion and of the weather and ocean.

1. Introduction

The pursuit of a sustainable society has made the development of safe and efficient sea transportation more essential than ever before. For decades, the subject has been studied in the fields of maritime transport and naval architecture (Newman, 1977; Faltinsen, 1990). There are two approaches to the study, namely, the theoretical method and the empirical method. The former method includes seakeeping, propulsion, and maneuvering theories, which have been extensively developed over the last decades (Ohkusu, 1996). Weather routing (optimal routing) is characteristic of the latter method, which is based on the fact that current ship operation significantly depends on intuition and experience (Yokoi et al., 2009, 2010). The IMO restricts the CO_2 emission from ships based on the EEDI (Energy Efficiency Design Index) (IMO, 2009). The EEOI (Energy Efficiency Operational Indicator) is also recommended for ships within the SEEMP (Ship Energy Efficiency Management Plan) (IMO, 2012). The EEDI is the design ratio of the CO_2 emission to the maritime transportation work of the ship, whereas the EEOI is the ratio of the actual CO_2 emission to the transportation work performed by the ship during operation. They require less emission of CO_2 for the same transportation work. Otherwise the ship should increase for the CO_2 emissions. Although the emission tends to decrease when the ship slows down, added resistance of a ship makes increase the emission in heavy seas. Accurate evaluation of the ship performance is thus urgently required for weather routing. A weather routing system uses weather forecasting and evaluation of the ship performance to decide the optimal sea route, and the development of weather forecasting over recent decades has drawn on improved computer performance. It is reported that the Japan Meteorological Agency currently has the ability to make weather forecasts 264 h ahead. However, the forecasting performance is not still enough for longer period if a navigation continues a couple of weeks or more, such as the international maritime transportation. Moreover, many of current weather routing services still discuss the safety of ships by the wave height based on operators' experience. There have been few studies to combine meteorological dynamics with the evaluation of ship performance

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at heavy seas. The weather is basically discussed with the global scale in the meteorology, although the ship performance is evaluated in one sea state. Some studies on the estimation of sea state also have been developed in decades (Iseki and Terada, 2002; Nielsen, 2006; Pascoal et al., 2007). The directional spectrum of waves can be estimated accurately with statistical techniques and the theory of ship response. It implicates the importance to consider the accurate ship response in the current weather routing. In this background, the authors show the necessity of the total study on the "three principles of maritime transportation". It implicates that the safety, the economical efficiency, and the marine environment should be discussed simultaneously in the maritime transportation. The research project has proceeded in three parts, safety, economy and environment as shown in Fig. 1. In the safety part, the new measurement system is planned to collect database of ship performance and weather during the seaway. A regular liner (LNG carrier or container ship) has been focused because of the convenience of install and maintenance of measurement systems. However, many of shipping companies do not agree to install the wave radar system because of the radar wave interference. An owner of tramp vessels allowed us to install the system. The start of measurement is delayed in June, 2010, and the first data collection is implemented one year later. This study is based on the measured result. In the economy part, cargo logistics are considered in the international navigation. In the environment part, a dispersion of exhausted gas from ships has studied by weather simulation models. These studies are briefly summarized as a publication (Kobe University Research Team of the Three Principles of Maritime Transportation, 2013). The speed loss or fuel consumption is related in the safety and economy parts, the emission of CO_2 gas is in the safety and environment parts. There are various kinds of factors to achieve the weather routing. First of all, it is important to accumulate measured parameters in actual sea. In this study, the estimation of ship motions is focused as the combination of weather hindcasting and seakeeping analysis. The ship motions are defined as the main parameter, when the speed loss is evaluated. And some relations are statistically analyzed, including the fuel consumption, engine power, revolution, etc. The accumulation of onboard measurement data is not only essential but also the initial step in the analysis of these problems. The major factors are the ship motions, navigation and engine parameters, and weather parameters for long periods. It is also necessary to establish a continuous measurement system for a 20,000 DWT class bulk carrier, and measurements are ongoing to collect further data. In the present study, presently collected data were statistically analyzed from various perspectives to explain the speed loss phenomenon on heavy seas. Numerical simulations of ship motions were also carried out to estimate the frequency spectra of the roll and pitch motions in following waves using the EUT (Enhanced Unified Theory) (Kashiwagi, 1997). Finally, a simple estimation of the speed loss and the fuel consumption is modeled by analyzed results.

2. Onboard measurement on actual sea

As mentioned earlier, the accumulation of onboard measurement data was necessary for this study. However, the collection of continuous data at sea is difficult, especially on long voyages. The employed sustainable measurement system was newly constructed and the details of the onboard measurement are described in this section. In this paper, weather data shows parameters in the air, such as wind, air pressure, air temperature, and includes parameters in the sea, such as waves, currents, etc.

2.1. Vessel and measurement period

A 20,000 DWT class bulk carrier was used for the onboard measurement. The vessel had no regular route service but travels all over the world as required by its cargo. It is 160.4 m long between perpendiculars, 27.2 m breadth, 9.5 m of fully loaded draft, and the design operational speed is 14 knots. If the cargo varies, there are also wide variations in its displacement and gravitational parameters. Fig. 2 shows a view of the carrier.

The vessel often voyages on open seas such as the Pacific Ocean, Atlantic Ocean, and Indian Ocean, which expose it to very large external forces. Thus, the onboard measurement system was positioned on the bridge. The reason is that many measurement devices are installed near the bridge, such as the radar, the GPS, the gyrocompass, the steering wheel, etc. The system included an inertial measurement unit, VDR (Voyage Data Recorder), engine data logger, weather gauge, and radar-type wave analyzer. The complete system flow is shown in Fig. 3.

As shown in Fig. 3, there are four flows in the system. The ship motions are observed by the inertial measurement unit and recorded in PC-1 every 0.1 s. The VDR and engine data logger are used to record the navigation and engine parameters in PC-2 every 1 s. The air pressure, humidity, and air temperature are recorded in PC-3 every 5 s. The waves around the vessel are observed by the radar wave analyzer and recorded in PC-4 as a wave number directional spectrum. The onboard measurement began at the end of June 2010 and still continues more than three years later.

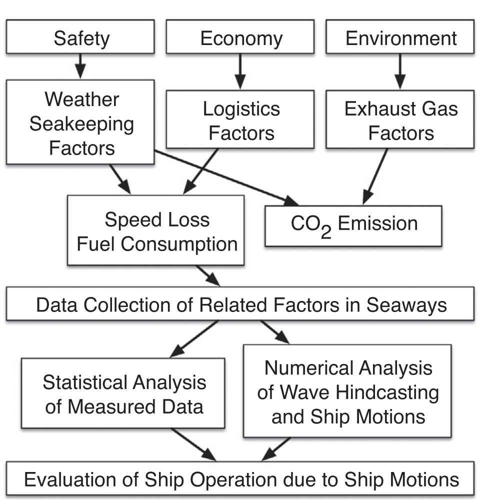

Fig. 1. Concept of desirable weather routing system.

Fig. 2. View of 20,000 DWT class bulk carrier used for this study.