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# A Study on the Verification Method of Ships' Fuel Oil Consumption by using AIS

Jinyoung Yang*†

* Department of Maritime Transportation System, Mokpo National Maritime University, Mokpo 58628, Korea

**Abstract** : *Since 2020, according to the International Convention for the Prevention of Pollution from Ships (MARPOL) amended in 2016, each Administration shall transfer the annual fuel consumption of its registered ships of 5,000 gross tonnage and above to the International Maritime Organization (IMO) after verifying them. The Administration needs stacks of materials, which must not be manipulated by ship companies, including the Engine log book and also bears an administrative burden to verify them by May every year. This study considers using the Automatic Identification System (AIS), mandatory navigational equipment, as an objective and efficient tool among several verification methods. Calculating fuel consumption using a ship's speed in AIS information based on the theory of a relationship between ship speed and fuel consumption was reported in several examples of relevant literature. After pre-filtering by excluding AIS records which had speed errors from the raw data of five domestic cargo vessels, fuel consumptions calculated using Excel software were compared to actual bunker consumptions presented by ship companies. The former consumptions ranged from 96 to 123 percent of the actual bunker consumptions. The difference between two consumptions could be narrowed to within 20 percent if the fuel consumptions for boilers were deducted from the actual bunker consumption. Although further study should be carried out for more accurate calculation methods depending on the burning efficiency of the engine, the propulsion efficiency of the ship, displacement and sea conditions, this method of calculating annual fuel consumption according to the difference between two consumptions is considered to be one of the most useful tools to verify bunker consumption.*

**Key Words** : *AIS, Annual fuel consumption, Bunker, MARPOL, Verification, Ship speed*

## 1. Introduction

It had been decided that the international maritime sector should be controlled by the International Maritime Organization (IMO), not by the UN Framework Convention on Climate Change (UNFCCC) Schemes, to pursue limitation or reduction of emissions of Green House Gas (GHG) according to Article 2(2) of the Kyoto Protocol. Such a decision seems to take into consideration the characteristics of international shipping whereby ships are sailing between different countries and across high seas beyond the sovereignty of specific states and the effectiveness of enforcement to reach the goal of GHG reduction through international mechanisms, not by individual state.

Ships consume fossil fuels such as petroleum and Liquefied Natural Gas (LNG) to gain energy for propulsion and electricity. It is essential to emit GHG as well as air pollutants like Nitrogen Oxides (NOx), Sulphur Oxides (SOx) and Particulate Matter (PM) during ship operations. The IMO adopted the new Chapter 4 of MARPOL Convention Annex 6 to regulate emission of GHG and air pollutants on 11th July 2011 (Resolution MEPC 203(62)), which came into force on 1st January 2013. The new Chapter mainly aims to increase energy efficiency and reduce fuel consumption through technical measures, resulting in reducing emissions of GHG and air pollutants. The Energy Efficiency Design Index (EEDI) is one of the vital technical measures for a new ship, along with the Energy Efficiency Operational Indicator (EEOI) and the Ship Energy Efficiency Management Plan (SEEMP), both of which aim to curb energy consumption during ship operations (IMO, 2019).

In addition, the IMO adopted the new requirement of Resolution MEPC Res.278 (70) in 2016, stating that a vessel of 5,000 Gross Tonnage (GT) and above should have on board the Part 2 of SEEMP verified by her Administration. The SEEMP contains a description of the methodology for collecting and reporting a ship's annual fuel consumption to the Administration. The reported data from ship companies shall be verified by the Administration and transferred to the IMO by June, starting in 2020 (DNV-GL, 2019).

However, it is significant administrative burden for the Administration to verify the reported data from its registered ships and to issue the Statements of Compliance to those ships in May

† 4ublueway@gmail.com, 044-200-5834

the next calendar year. Furthermore, the verification procedure itself might be a challenging task considering each vessel has various particulars and operating characteristics with different service routes and contract conditions.

This study aims to consider an efficient and objective method to mitigate the administrative burden of verifying a ship's annual fuel consumption, which reduces the need for submission of copies of the ship's Deck Log Book, Engine Log Book or Noon report and presents assumed fuel consumption figures calculated by using official data that cannot be manipulated by ship' companies. The Automatic Identification System (AIS), one of the pieces of statutory navigational equipment under the SOLAS Convention, is proposed as one of these tools for the purpose of this study.

There have been several literatures studying how the emission quantity of air pollutants from shipping can be assumed using AIS information globally, regionally or locally (Perez et al., 2009; Jalkanen et al., 2009; Fung et al., 2014; IMO, 2015; DNV-GL, 2015; Coello et al., 2015; Yao et al., 2016; Rodríguez et al., 2017). However, these studies focus on specific areas or certain ship types and few reports are found which compare the estimated fuel consumption with actual consumption data of ships.

Therefore, this study tries to review whether the method of estimating fuel consumption is an effective tool to verify a ship's annual bunker consumption. For this purpose, five coastal cargo vessels, whose most complete tracks have been recorded in shore-based AIS servers and whose AIS information was provided by their companies' content, were chosen in order to compare calculated fuel consumption by AIS information to a ship's actual fuel consumption for the period of a year.

## 2. Factors affecting Fuel Oil Consumption of Ships

The consumption of fuel oil or energy is affected by diverse factors such as the burning efficiency of a ship's engine, the ship's propulsion efficiency, the ship's displacement or cargo weight, hull resistance, weather and sea conditions, etc. Nearly 57 percent of energy generated by burning fuel is mainly wasted through heat during the burning process and through the internal friction of engine components and heat in exhaust gas, whereas the rest is transferred to the propeller shaft as shown figure 1. The energy used to get propulsion power is assumed to be about 28 percent of initially generated energy including a part propeller slip. The actual energy used for sailing is only estimated at more or less 20 percent of supplied energy after overcoming water and air resistances.

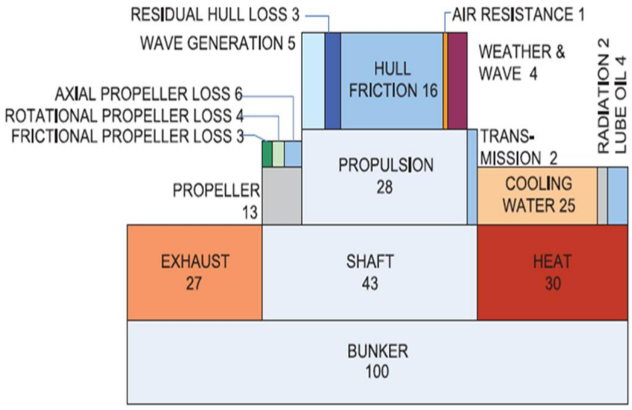


Fig. 1. Energy segregation of 6,000 DWT Feeder, Beaufort 6 (Source: TecnoVeritas, 2018).

Reducing energy loss outside through exhaust gas and cooling water during the burning process leads to higher engine burning efficiency. To increase hull propulsion efficiency, new technologies can be introduced such as improvements in propeller performance and hull foam and applying paints or an air lubrication system to reduce hull resistance. Enlargement of ship size is progressing to cut energy consumption rate per transported unit.

For example, an 8,000 Twenty-foot Equivalent Unit (TEU) class Container reports a reduction of about 25 % in terms of consumption rate per ton-mile of cargo transported compared to a 4,500 TEU class ship (ABS, 2013). According to the United Nations Conference on Trade and Development (UNCTARD), the cargo capacities of Containerships in 2018 are rapidly increasing to nearly 2.4 times what they were in 2004 (UNCTARD, 2018).

Meanwhile, there has been a commitment to take operational measures which curb bunker or energy consumption from ships. These measures are deeply related to the EEOI of the MARPOL Convention. To optimize ship propulsion efficiency, reductive actions are taken such as adjusting trim and list or removing underwater hull fouling. In addition, considering fuel consumption rate is directly proportional to the cube of speed ratio, reducing sailing speed is widely adopted by shipping companies as one of most effective ways for reducing bunker consumption. For instance, it is reported that a decreases one knot of ship speed leads to about 12～15% reduction of bunker consumption on a 4,500 TEU class Container (ABS, 2013).

Although vessels are encouraged to load more cargoes or passengers to make a profit, cargo weight loaded also influences energy consumption. More cargo weight or greater ship displacement causes a change in the hull underwater areas and thus leads to changes in the hull resistance value.

Sea conditions also affect a ship's speed. The same direction of wave, current and wind aligning with a ship's trajectory will increase its speed and decrease bunker consumption and vice versa.

## 3. AIS Technical Characteristics and AIS data Processing

### 3.1 AIS Technical characteristic

The AIS is required to be fitted to all passengerships, any ship engaged in international voyages with 300 GT and above and a domestic ship with 500 GT and above according to regulation 19.2.4 of SOLAS Chapter 3. The equipment should be fitted not later than July 2008 although the due date for individual ships varies with a ship's build date.

According to IMO Assembly Resolution A. 917 (22) and A.956 (23), this device is designed to prevent maritime accidents and protect marine environment through easy identification, tracking of ships and facilitating reporting procedures by exchanging useful information from ship to ship or ship to shore. In other words, the equipment is a vital auxiliary navigational device supporting the avoidance of ship collision and vessel traffic monitoring, apart from a Radar, providing ship traffic information in the vicinity of interested areas to navigators or operators of vessel traffic service by continuously presenting the ship's name, position, speed and heading, etc (Baldauf, 2017).

The equipment continuously transmits and receives ship identification and movement information as shown in table 1. A ship's static information, such as IMO number, maritime mobile service identity number (MMSI) and the ship's length, inputs itself when it fits. On each voyage, the ship's crew are recommended to input voyage-related information, such as ship draft, type of dangerous cargo and destination, etc. While dynamic information, such as ship position, time, heading and speed, is automatically updated by the connection of the ship's relevant sensors (IMO, 2002).

The AIS information is generally evaluated as having higher accuracy. However, there have been found several cases of errors: incorrect connecting to a ship's sensors related to position and speed; improper calibration of the sensors; and inputting incorrect raw information such as a ship's particulars (Jeon and Jeong, 2016). Some reports have also been made about malfunctions in receiving and storing components in shore-based AIS sites and unknown reasons which result in questions about their accuracy.

Table 1. AIS Information sent by a ship

| Item | Type of Information | Information generation |
|---|---|---|
| Static | MMSI Number | Set on installation |
| | Call sign and name | Set on installation |
| | IMO Number | Set on installation |
| | Length and beam | Set on installation |
| | Type of ship | Select from pre-installed list |
| | Location of position-fixing antenna | Set on installation |
| Dynamic | Ship's position | Automatically updated |
| | Position Time stamp in UTC | Automatically updated |
| | Course over ground | Automatically updated |
| | Speed over ground | Automatically updated |
| | Heading | Automatically updated |
| | Navigational status | Manually entered |
| | Rate of turn if fitted | Automatically updated |
| Voyage-related | Ship's draught | Manually entered |
| | Hazardous cargo | Manually entered |
| | Destination and ETA | Manually entered |
| | Route plan (way points) | Manually entered |

Therefore, it needs users' efforts to ensure that the system is working properly and check whether the information contains errors or misinformation before processing it.

The AIS detection coverage varies with the height of its antenna although its basic coverage is about 20 - 30 miles. Ship AIS information could not be stored in shore-based AIS servers when the ship sails beyond the coverage. In this case, AIS information could be purchased from satellite AIS information providers like the ORBCOMM and the exactEarth. This restraint forces us to choose only domestic ships for this study.

The transmission intervals of AIS dynamic information mostly depend on a ship's speed. The intervals vary from a minimum of two seconds to a maximum of three minutes as shown in table 2, which means the equipment transmits the dynamic information

Table 2. Reporting interval of AIS information

| Status of ship | Reporting interval |
|---|---|
| Ship at anchor | 3 min |
| ship of 0-14 knots | 12 sec |
| ship of 0-14 knots and changing course | 4 sec |
| ship of 14-23 knots | 6 sec |
| ship of 14-23 knots and changing course | 2 sec |
| ship of 23 knots and above | 3 sec |
| ship of 23 knots and above and changing course | 2 sec |

after at least about 12 seconds when sailing. On the other hand, static and voyage-related data are generally transmitted every six minutes.

### 3.2 The Status of Ships

There are 44 coastal AIS sites including Yeonpyeongdo, Ieodo and Dokdo along the Korean peninsula, which cover most of domestic shipping lanes (MOF, 2019). This study analyzes the AIS information of five domestic vessels including one oil tanker, two LPG carriers and two steel product carriers as shown in table 3.

Table 3. The status of ships being analyzed

| Vessels | | Oil | Gas 1 | Gas 2 | Stl 1 | Stl 2 |
|---|---|---|---|---|---|---|
| Gross Ton | | 25,332 | 4,236 | 3,866 | 2,794 | 2,794 |
| Deadweight | | 34,997 | 3,615 | 3,782 | 4,126 | 4,122 |
| Year of Built | | 1988 Oct. | 1991 Sep. | 1990 Nov. | 1996 Apr. | 1996 Jun. |
| Design Spd(k'ts) | | 15.6 | 16.405 | 15.63 | 13.5 | 13.5 |
| Main Eng. | MCR(kW) | 7,855 | 3,089 | 2,346 | 3,206 | 3,206 |
| | SFOC (g/kWh) | 171.99 | 176.75 | 171.99 | 179.47 | 179.47 |
| | Fuel type | MF380 | MF380 | MF380 | MF380 | MF380 |
| Aux. Eng. | MCR(kW) | 456 × 3 sets | 353 × 2 sets | 265 × 2 sets | 265 × 2 sets | 265 × 2 sets |
| | Fuel type | MDO | MDO | MDO | MDO | MDO |

An oil tanker of 25,332 GT was regularly in service carrying product oils from Yeosu to Incheon. While Gas carrier 1 of 4,236 GT was mainly transporting LPG from Yeosu to Incheon or Pyeongtaek, 3,866 GT Gas carrier 2 was largely engaged in shifting between piers in Yeosu. The two steel product-carriers are sister ships and serving from Kwangyang or Pohang to Incheon, Pyeongtaek or Busan.

These vessels were built before June 1996 and have installed one main engine, two or three auxiliary engines for generators and boilers respectively. The outputs of main engines range from 2,346 to 7,855 kW while auxiliary engines are 530 ~ 1,368 kW. The specific fuel oil consumption rates (SFOC) of main engines indicated between 171.99 ~ 179.47 g/kWh and their fuel oil was MF380, heavy fuel oil. The SFOC of auxiliary engines marked between 195 ~ 209.38 g/kWh using Marine Diesel Oil (MDO).

### 3.3 AIS Data Pre-Filtering

The accuracy of time-stamp, a ship's position (Latitude and Longitude) and speed of AIS information is deeply related to that of fuel consumption when calculating based on AIS information. To evaluate the accuracy of AIS information, Speed Over Ground (SOG) among AIS information was set as an independent variable and reviewed. Each vessel had different distribution of SOGs from zero to over 100 knots as shown in table 4. 348.8 knots was recorded as the fastest speed in the raw data.

Table 4. The SOG distribution of Ships' AIS raw data

| Items | Oil | Gas 1 | Gas 2 | Stl 1 | Stl 2 |
|---|---|---|---|---|---|
| Period | Jan.1.2016 ~ Dec.31.2016 | | | Jul.1.2017 ~ Jul.13.2018 | |
| Records | 2,074,493 | 1,085,507 | 816,211 | 1,512,424 | 1,129,101 |
| below 1 k'ts | 140,617 | 319,088 | 120,199 | 328,660 | 223,740 |
| 1~4.9 k'ts | 29,960 | 22,714 | 19,515 | 31,239 | 15,614 |
| 5.0~9.9 k'ts | 62,500 | 38,436 | 194,967 | 541,780 | 328,052 |
| 10.0~14.9 k'ts | 1,387,614 | 670,186 | 457,974 | 608,113 | 558,717 |
| 15.0~19.9 k'ts | 453,273 | 35,057 | 4,002 | 1,383 | 2,552 |
| 20.0~24.9 k'ts | 25 | 0 | 0 | 58 | 46 |
| 25.0~49.9 k'ts | 2 | 0 | 0 | 135 | 118 |
| 50.0~99.9 k'ts | 0 | 0 | 0 | 105 | 125 |
| above 100 k'ts | 502 | 26 | 19,554 | 951 | 137 |

A ship's maximum speed is normally the outcome of a sea trial while running at the Maximum Continuous Rating (MCR) of the main engine, assuming fully loaded condition. As the Normal Continuous Rating (NCR) of main engine is running below MCR, normal sailing speed measures as less than maximum speed. However, there might be a moment that normal sailing speed at the power of NCR exceeds her maximum speed if the ship sails in ballast condition with the current. In particular, a strong current makes an impact on ship speed when navigating in an area of apparently strong currents such as the west coast of the Korean peninsula and the Maenggol channel.

The Korean Hydrographic and Oceanographic Agency (KHOA) has been conducting a survey of tidal speeds by using a High frequency Radar at 10 observation sites along its coast including

Incheon, Mokpo, Yeosu, Busan and Pohang. Among them, Tae-an off coast was recorded as the fastest place at 200 cm per second or, about 3.89 knots as shown in table 5 (KHOA, 2019).

Table 5. The current speed at prominent coastal places

(Unit: cm/second)

| Place | 1 Quarter of 2018 | 2 Quarter of 2018 | 3 Quarter of 2018 |
|---|---|---|---|
| Incheon Harbor | 124.4 | 119.8 | 137.2 |
| Tae-an Peninsular | 200.0 | 200.0 | 200.0 |
| Outer Mokpo | 189.4 | 167.8 | 169.3 |
| Yeosu Channel | 144.7 | 143.9 | 154.7 |
| Busan New Port | 101.9 | 190.0 | 199.9 |
| Pohang Harbor | 107.9 | 83.4 | 115.0 |

Source: KHOA Oceanographic Observation Newsletter, 2018

The maximum allowable SOG for this study is set as the value of maximum speed of individual ships plus four knots, considering the above-mentioned tidal effect. Ships' SOGs which exceed the maximum allowable SOG are considered as errors and excluded from the calculation. The errors were mostly placed at above 100 knots for vessel Oil, Gas 1 and Gas 2, while such errors were relatively wide spread for vessel Stl 1 and Stl 2. The vessel having the highest SOG error rate goes to Gas 2 with approximately 2.4 percent of raw data.

Also, records having less than 0.3 knots after the moment of anchoring or berthing were excluded from the calculation, considering the ship's main engine was not running during the period. Another consideration also given was that drastic changes of ship speed are not expected in ships, unlike a car, since they have huge mass and moves through fluid. Thus, records showing

Table 6. The example of abnormal speed change

| Time | Lat.(N) | Long.(E) | Heading(deg) | SOG(kts) |
|---|---|---|---|---|
| 2017-10-07 17:58 | 34.91011 | 127.7149 | 72 | 0 |
| 2017-10-07 18:01 | 34.91007 | 127.7148 | 100 | 0.1 |
| 2017-10-07 18:04 | 34.90983 | 127.7147 | 116 | 0 |
| 2017-10-07 18:04 | 34.9109 | 127.7145 | 24 | **7.7** |
| 2017-10-07 18:05 | 34.91071 | 127.7148 | 55 | 0.2 |
| 2017-10-07 18:05 | 34.91014 | 127.715 | 120 | 0 |

unusual speed changes in terms of ship movement characteristics, such as 7 knots' change a minute showed in Table 6, were eliminated from the calculation.

Meanwhile, the AIS information of a vessel navigating outside the detection area of terrestrial AIS sites does not get stored in AIS servers. As the fuel consumption of this sailing period could not be calculated by this study, the whole voyage including the period was excluded from the calculation in order to compare the actual consumption data. For instance, a Gas 2 vessel occasionally sailed overseas 14 times to China, Japan, Taiwan and Thailand although she was mainly engaged in domestic services.

The AIS records of each ship after review and above-mentioned exclusions of raw data were utilized for this study in different ways, which measured between 59 to 92 percent of them as shown in table 7.

Table 7. Dataset for analysis after pre-filtering

| Items | Oil | Gas 1 | Gas 2 | Stl 1 | Stl 2 |
|---|---|---|---|---|---|
| Raw Records(A) | 2,074,493 | 1,085,507 | 816,211 | 1,512,424 | 1,129,101 |
| Dataset(B) | 1,898,635 | 759,366 | 478,984 | 1,201,672 | 914,386 |
| Percentage (B/A, %) | 91.5 | 70.0 | 58.7 | 79.5 | 81.0 |

## 4. Fuel consumption Calculation using AIS Information

### 4.1 Fuel Consumption Calculation Equation

A ship's main engine needs fuel for propulsion, a motor of generators for providing electricity to auxiliary machinery used for the ship's operations, and boilers for providing steam and hot water to maintain the heating bunker and cargoes. Generally, a main engine is running at sea, not operating at anchor or in berth, while generators and boilers are continuously running, whether sailing or not, unless shore-based power is provided.

The fuel consumption of the ship's main engine is directly related to the engine's output and an engine has different output and fuel consumption at certain moments according to what fuel type is provided and what the revolutions per minute (RPM) is. The output of the engine has cube relationship to the ship's speed, which means the fuel consumption is proportional to engine output and exists in cube correlation with the ship's speed (Youn et al., 2013).

On the other hand, the SOG of AIS information indicates the ratio of the ship's current speed against maximum speed. This speed ratio implies instant output of the engine against its MCR and directly correlates to fuel consumption. From the theory of this relationship, fuel consumption at certain moments could be calculated in proportion to the speed ratio. This understanding could lead to devising of following formulas (1) (EPA, 2009; IMO, 2015; DNV-GL, 2015):

$$\left(\frac{\text{Instant Spd by AIS at } t\ (A)}{\text{Maximum Speed at MCR } (B)}\right)^{3} \times \text{Eng. Max. Output (kW, C)} \times \text{SFOC (g/kWh, D)} \qquad (1)$$

In above formula (1), the instant speed A means the speed of AIS information of the ship at the moment t. The maximum speed B stands for the speed at MCR condition, which indicates maximum speed by her sea trial. The maximum engine output is measured at MCR condition while SFOC stands for the Specific Fuel Oil Consumption of the engine, which means fuel consumption rate presented by grams per kilo watt hour (kWh). The maximum speed B can be gained from the Particulars of Hull or the report of the sea trial issued by a ship surveying organization. The maximum output and SFOC are mostly recognized in the ship's Particulars of Machinery.

To gain the fuel consumption at each moment by using Microsoft Excel, the following formula (2) can be used if SOG of AIS is incorporated into formula (1):

Fuel consumption(g) = ((SOG/Max.SPD)^3) × Eng. Max. Output(kW) × Time interval(H) × SFOC(g/kWh) (2)

To utilize the function of Excel software, the time interval H is gained from multiplying the span of two consecutive time stamps by 24 as follows formula (3):

$$\text{Time Interval (H)} = (t_2 - t_1) \times 24 \qquad (3)$$

Eventually, if formula (3) is incorporated into formula (2), the fuel consumption between the span of two consecutive time stamps can be calculated by formula (4);

Fuel consumption(g) = ((SOG/Max.SPD)^3) × Eng. Max. Output(kW) × $(t_2\text{-}t_1)$ × 24 × SFOC(g/kWh) (4)

After downloading AIS information from the AIS servers and pre-processing them, table 8 can be obtained by formula (4) for the calculation of fuel consumption by using Excel software.

Table 8. The example of estimating bunker consumption calculated by using Excel software

| Time | Lat. (N) | Long. (E) | SOG (kts) | *Dist. (mile)* | *Ratio of (SOG/ Max.Spd)* | *Time int.(H)* | *Fuel con.(g)* |
|---|---|---|---|---|---|---|---|
| 2018-01-02 16:46:00 | 34.86475 | 127.7977 | 8.0 | *0.01544* | *0.59259* | *0.00278* | *332.68* |
| 2018-01-02 16:46:10 | 34.86459 | 127.7975 | 8.0 | *0.03598* | *0.59259* | *0.00306* | *365.95* |
| 2018-01-02 16:46:21 | 34.86423 | 127.7969 | 8.2 | *0.01396* | *0.60741* | *0.00250* | *322.43* |
| 2018-01-02 16:46:30 | 34.86408 | 127.7967 | 8.3 | *0.02349* | *0.61481* | *0.00333* | *445.83* |
| 2018-01-02 16:46:42 | 34.86384 | 127.7963 | 8.4 | *0.03086* | *0.62222* | *0.00222* | *308.09* |
| 2018-01-02 16:46:50 | 34.86354 | 127.7958 | 8.4 | *0.01892* | *0.62222* | *0.00278* | *385.12* |
| 2018-01-02 16:47:00 | 34.86336 | 127.7955 | 8.5 | *0.01649* | *0.62963* | *0.00278* | *399.04* |
| 2018-01-02 16:47:10 | 34.86321 | 127.7952 | 8.5 | *0.04051* | *0.62963* | *0.00333* | *478.84* |
| 2018-01-02 16:47:22 | 34.86285 | 127.7945 | 8.7 | *0.01181* | *0.64444* | *0.00222* | *342.30* |
| 2018-01-02 16:47:30 | 34.86274 | 127.7943 | 8.7 | *0.02127* | *0.64444* | *0.00333* | *513.45* |
| 2018-01-02 16:47:42 | 34.86256 | 127.7939 | 8.7 | *0.03378* | *0.64444* | *0.00222* | *342.30* |
| 2018-01-02 16:47:50 | 34.86229 | 127.7933 | 8.6 | *0.02153* | *0.63704* | *0.00306* | *454.62* |
| 2018-01-02 16:48:01 | 34.86214 | 127.7929 | 8.5 | *0.01402* | *0.62963* | *0.00250* | *359.13* |
| 2018-01-02 16:48:10 | 34.86207 | 127.7927 | 8.4 | *0.03911* | *0.62222* | *0.00333* | *462.14* |
| 2018-01-02 16:48:22 | 34.86194 | 127.7919 | 8.1 | *0.01156* | *0.60000* | *0.00222* | *276.25* |
| 2018-01-02 16:48:30 | 34.86192 | 127.7916 | 8.0 | *0.01765* | *0.59259* | *0.00278* | *332.68* |
| 2018-01-02 16:48:40 | 34.86191 | 127.7913 | 7.9 | *0.03239* | *0.58519* | *0.00278* | *320.36* |
| 2018-01-02 16:48:50 | 34.86198 | 127.7906 | 7.7 | *0.01879* | *0.57037* | *0.00306* | *326.30* |

### 4.2 Fuel Consumption Output result

The total fuel consumption for a certain period can be gained if adding up fuel consumption at each moment by the same calculation as shown in table 8. Since this study intends to verify annual fuel consumption of ships, the calculation is summed up for a year. The total calculated fuel consumptions are showed in table 9 together with actual yearly consumption.

Table 9. The comparison between actual fuel consumption and calculated bunker consumption

| Vessels | | Oil | Gas 1 | Gas 2 | Stl 1 | Stl 2 |
|---|---|---|---|---|---|---|
| Fuel Consu-mption (ton) | Ship data(A) | 5,760.50 | 732.16 | 399.43 | 935.81 | 755.88 |
| | AIS Cal.(B) | 4,709.75 | 761.30 | 353.73 | 809.25 | 679.28 |
| Sailing Dist.(C) | | 53,414.96 | 22,930.27 | 17,989.40 | 37,422 | 25,901 |
| Sailing Hour(D) | | 4,077.35 | 1,966.97 | 1,400.68 | 3,384.45 | 2,594 |
| A/B(%) | | 122.31 | 96.17 | 112.92 | 115.64 | 111.28 |
| A/C (kg/Mile) | | 107.844 | 31.930 | 22.204 | 24.740 | 27.500 |
| A/D (Ton/Hour) | | 1.413 | 0.372 | 0.285 | 0.274 | 0.275 |

The gap ratios between actual consumption and estimated calculation range from 96 to 123 percent.

### 4.3 The analysis of calculation Results

The five ships analyzed used heavy fuel oil (HFO) for their main engines without changing to MDO, exceptionally changing only five times a year for Stl 1, when entering or leaving ports. While boilers used HFO, the generators burned MDO as their fuels. Meanwhile the actual HFO consumption data during sailing provided by shipping companies contained the quantity consumed by her main engine and boilers. Contrary to the actual data, calculated consumption indicates only fuel amounts consumed by the main engine. Therefore, the consumption by boilers is excluded from the companies' actual consumption to compare calculated consumption based on AIS information as shown in table 10.

However, the boiler fuel consumptions of Oil, Gas 1 and Gas 2 have not been available from the ship company. Noting that the fuel consumption by boilers was assessed at around 3.7 percent of total fuel consumption (IMO, 2015), if the boiler's consumptions of the three vessels are applied, the gaps between two consumptions could be narrowed to within ± 20 percent.

One of the reasons impacting on the gap for each vessel is assumed that the actual consumption had not been accurately recorded as well as the calculated consumption itself containing possible errors in parts of the raw data. This was because the former had not been accurately measured and recorded by the ship's crew, who had not been instructed and trained for this purpose. However, even though actual bunker consumption for each voyage contains errors, the total degree of error for yearly consumption after adding each voyage's calculation would be dropped to allowable range.

Table 10. The compassion between actual fuel consumption of main engine and estimation calculated by AIS information

| Fuel Consumption(ton) | Oil | Gas 1 | Gas 2 | Stl 1 | Stl 2 |
|---|---|---|---|---|---|
| Ship data (inc. Boiler, A) | 5,760.50 | 732.16 | 399.43 | 935.808 | 755.880 |
| Ship data (exc. Boiler, A') | N/A | N/A | N/A | 925.808 | 712.675 |
| AIS Calculation(B) | 4,709.75 | 761.302 | 353.728 | 809.251 | 679.279 |
| A/B(%) | 122.31 | 96.17 | 112.92 | 115.64 | 111.28 |
| A'/B(%) | - | - | - | 114.40 | 104.92 |

Another reason for the gap between actual consumption and calculated assumption is directly related to the burning efficiency of the engine, the efficiency of the ship's propulsion, the weather, the sea condition and the ship's draft. Among them, the engine performance, displacement or cargo weight and sea conditions are regarded as affecting bunker consumption deeply (Rakke, 2016).

Whereas the report of the third IMO GHG study (2015) showed that the difference between supplied fuel quantity (top-down approach) to international shipping in 2011, 207.5 million tons, and estimated fuel consumption (bottom-up approach) by ships, 274 million tons, had reached up to 32 percent. The EMEP/EEA guideline book for air pollutant emissions (2016) stated that the estimated uncertainty of a ship's fuel consumption was given ± 10 percent at sea, ± 30 percent in maneuvering and ± 20 percent in port respectively. These results imply that the statistics on ships may include several variables which could not be collected and evaluated easily. There needs to be more studies to minimize the adverse influence of the variables

## 5. Conclusion

To cope with the reduction of GHG, the IMO adopted the EEDI and EEOI. These measures enhance the increased energy efficiency in ships and ultimately reduce the consumption of fossil fuels. For this purpose, ships of 5,000 GT and above are required to report their annual bunker consumptions to their Administration which will review and verify the reports.

Verifying a ship’s annual bunker consumption will require a certain amount of man power. Additionally, it is vital for the Administration to secure the objectivity and transparency of the verification. Utilizing AIS information, one of the pieces of mandatory navigational equipment, is considered to address these issues.

This study attempted to compare calculated fuel consumption using AIS information and actual bunker consumption obtained from five domestic cargo vessels. It is noted from the review of raw AIS data that around a maximum of 2.4 percent of them had speed errors, which showed up to 348.8 knots. Assumed bunker consumption was calculated out by Excel software excluding the records having error and during the period recognized as at anchor or in berth. The formula to calculate fuel consumption has been used in several previous studies, which assumes the load factor of the engine corresponding to the ratio of instant ship speed against designed maximum speed. If applying the SFOC of the engine and the fuel consumption rate, to the formula, the fuel consumption between the span of two time stamps could be calculated. Adding the calculation outcomes at the span up to the whole intended period can present the total bunker consumption.

The result of comparing the calculated consumption using AIS information to actual bunker consumption presented by ship companies showed around a minimum of 80 percent similarity. The similarity of this outcome could develop the concept that this approach of calculating fuel consumption is a useful tool to verify bunker consumption submitted by ship companies, considering that uncertainty around fuel consumption and the difference in the report issued by the IMO in 2015 between the bunker supply to ships and their bunker consumption was measured at about 32 percent. However, it is necessary to develop more accurate calculation formula. It is believed that the difference between calculated consumption using AIS information and actual bunker consumption presented by ship companies, although each of two consumption figures may contains errors, is affected by several factors, such as the burning efficiency of the engine depending on aging, the ship’s displacement and sea conditions. Hence, further study is needed to establish how much these factors influence on bunker consumption.

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