CALCULATION OF OPERATIONAL INDICATOR EEOI FOR SHIPS DESIGNED TO OTHER PURPOSE THAN TRANSPORT BASED ON A RESEARCH – TRAINING VESSEL

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MSc. Katarzyna Prill, MSc. Karol Igielski
Maritime University of Szczecin, **Poland**

Abstract. Applying the Energy Efficiency Operational Indicator as a tool for monitoring the energy efficiency of ships performing other functions or tasks than transport is a problem in the proper assessment of the CO_2 emitted by the vessel during its operation. The analysis of 30 voyages of the research-training vessel showed that the vessel Energy Efficiency Operational Indicator is higher than for transport vessels in the world fleet. The authors suggest that the term *„performed transport work"* in the indicator calculation method recommended by the International Maritime Organization needs to be modified in terms of operational parameters of this type of ships.

Keywords: Vessel energy efficiency, CO_2 emission, research – training vessel, EEOI, operational indicator

INTRODUCTION

Maritime transport is one of the most efficient transportation branches. Goods having various physical and chemical properties are transported by ships over long distances. This phenomenon determines continuous changes both in terms of exploitation, ship structure, its dimension, propulsion system and operational capacity of transshipment ports, and mainly affects that goods are transferred faster from the producer to the recipient. Determining that the goods are transported in as large quantity as possible, in the shortest possible time involves increasing the speed of the ship and thereby intensifying the combustion process of fuel. The result of same is releasing the remains of the process to the environment i.e. CO_2 and other greenhouse gas. MacLachlan (MacLachlan, 2005) believes that the top 15 largest ships would emit as much greenhouse gasses as all the 780 million cars. It should be noted that there are up to 100,000 working vessels and shipping brings us 90% of world trade (MacLachlan, 2005).The ships travel huge distances and as pointed out by Buhaug et al (Buhaug et al, 2009) every ship type may be characterized by a different CO_2 emission level, which results in significant increase of the gas emission to the atmosphere.

The matter of effects caused by the greenhouse gas emissions to the atmosphere being a result of a ship operation has been analyzed by scientists for dozens of years. Scientific studies and analyses have shown that shipping makes up around 3% of global CO_2 emissions (Amstrong and Banks, 2015), while Smith et al. (MEPC, 2014) forecast that these emissions are expected to increase from the 2012 levels by 50-250% by 2050. In recent years, the IMO is mainly focused on developing a multi-dimensional policy for the reduction of CO_2 emitted by ships to the atmosphere. This activity has been imposed by the requirement included in Art. 2 of the *United Nations Framework Convention on Climate Change* (UN, 1997). The paper indicates that the responsibility for implementing activities related to the reduction of CO_2 emission in the shipping industry has been assigned to the IMO. Since the Kyoto Protocol adoption, the Marine Environment Protection Committee has been working on developing the solutions enabling to improve the energy efficiency of ships. The main MEPC assumption was to develop tools aimed at solving the problem at every stage of ship operation, commencing on the design phase and proceeding trough the operational stage.

Contact address: e-mail: k.prill@am.szczecin.pl

As a result, the MEPC developed tools which when combined with one another, would reduce CO_2 emission gradually, and, consequently, would reduce the global air temperature to the agreed in 2009 temperature of 2°C above the temperature in the pre-industrial era (MEPC, 2014). Among the above-mentioned solutions, the following ones have been included:

1. Energy Efficiency Design Index (EEDI) – MEPC Circ.681, 682, 212(63) (MEPC, 2012), 213(63), 215(63), is the regulation implemented for new vessels. The EEDI was developed and implemented as a response to the need to meet the technical and structural requirements of ships at the design stage which would result in an increased energy efficiency of the fleet as a whole (Szczepanek and Rajewski, 2015).
2. Ship Energy Efficiency Management Plan (SEEMP) – MEPC Circ.683, 213(63). During the works aimed at improvement of the energy efficiency, the IMO proposed a system approach. The approach purpose is to increase the ship energy efficiency by developing specific measures by the shipowner on the particular ship, which would lead to the reduction of CO_2 emission. The SEEMP was adopted (MEPC, 2012) as a mandatory tool under MARPOL Annex VI reg. 22 as amended and entered into force on 1st January 2013.
3. Energy Efficiency Operational Indicator (EEOI) – MEPC Circ.471, 684. The main goal of the indicator is to improve the energy efficiency of a ship during a travel by determining the ratio of the mass of CO_2 emitted per a specified a unit of transport work (MEPC, 2009). Determining the EEOI is voluntary and should be calculated on the grounds of actual operational data monitored and recorded during the voyage.

The EEOI indicator is presented in detail in the following section of the paper (*section 2*). Section 3 is a discussion on the application of the current method for determining the EEOI for a ship to the research – training vessel specification.

OPERATIONAL INDICATOR OF SHIP ENERGY EFFICIENCY

The IMO has adopted the EEOI as a tool aimed at supporting the process of limiting and the reduction of CO_2 emission by the ships in operation. The indicator has been defined as a ratio of the mass of CO_2 emitted per a specified work unit e.g. CO_2[t]/(t/Nm), CO_2[t]/(TEU/Nm), etc. (Tran, 2017).

$$EEOI = \frac{actual\ CO_2\ emission}{performed\ transport\ work} \tag{1}$$

The EEOI represents the ship energy efficiency in a defined time. It is the most commonly used to calculate the energy efficiency per a voyage, a year or a specific operational cycle. In order to determine the EEOI for a particular period (for a voyage), according to the MEPC.1/Circ. 684, the following formula should be applied:

$$EEOI = \frac{\Sigma_j FC_j \times C_{Fj}}{m_{cargo} \times D_j} \tag{2}$$

where:

j – fuel type;

FC_j – mass of consumed fuel j at voyage;

C_{Fj} – fuel mass to CO_2 mass conversion factor for fuel j;

m_{cargo} – cargo carried (tonnes) or work done (TEU or passengers) or gross tonnes for passenger ships;

D – distance in nautical miles corresponding to the cargo carried or work done.

In order to calculate the EEOI for a longer period of time e.g. a year, a quarter, all voyages of the ship in that period should be summed up along with those where the ship did not carry any cargo.

CALCULATING EEOI FOR RESEARCH – TRAINING VESSEL USING A STANDARD METHOD

The IMO listed 7 types of ships in the *Guidelines for voluntary use of the ship Energy Efficiency Operational Indicator (EEOI)* (MEPC, 2012): dry cargo carriers, tankers, gas tankers, containerships, ro-ro cargo ships, general cargo ships, passenger ships for which the indicator is recommended. The list does not include the vessels the aim of which excludes transport of

goods and passengers i.e. fishing vessels, offshore vessels, specialised and research vessels, training vessels and coastal shipping vessels. Periodic reports on the energy efficiency of the global fleet take into account additional ship types (MEPC, 2014, UCL E.I., 2015), but the IMO focused mainly on vessels transporting cargo or passengers which are reflected in the formula by (2) m_{cargo}. In the view of the above, it may become problematic to adjust the recommended formula (2) to the specification of the ships which do not transport cargo or passengers, but they are operated intensively, emitting CO_2 (Lützen at al., 2017).
In order to compute the EEOI using the standard method specified in formula (2), 30 voyages of the research-training vessel taken in 2015 and 2016 were selected. The voyage was defined a ship trip in a period of time determined by education program and maritime training program, started and finished in Szczecin port, during which the tasks related to the implementation of the maritime training program and/or the research work are performed. The voyage duration includes stops at anchorages, ports, roadsteads etc. The m_{cargo} is considered as a total weight of students and scientists divided by gender and participating in the voyage, i.e. an average weight of a man – 88.8 kg, an average weight of a woman – 76.4 kg (U.S.HDHS, 2016) along with a luggage of an average weight of 20kg per person. The maximum amount of people that may be on board (excluding the crew) equals to 38. The vessel uses only MGO DMA fuel of the density of 856.8 kg/m^3 at the temperature of 15°C and 0.07% sulphur content. Therefore, according to the MEPC.1/Circ.684, C_F for fuel is 3.206. Table 1 presents extraction from data used for research purposes and the EEOI indicator calculated using a standard method.

Table 1.
Calculation of EEOI for research – training vessel – standard method (extraction from data).

Voyage number	Period	Distance [Nm]	Number of persons		Fuel consumption [t]	m_{cargo} [t]	EEOI [tCO_2/(t x Nm)]
			K	M			
1	16.02 - 27.02.2015	524.3	7	28	12.85	3.7212	$2.112E^{-02}$
2	02.03 - 13.03.2015	646	9	26	12.38	3.6964	$1.662E^{-02}$
3	17.03 - 23.03.2015	495	9	25	11.48	3.5876	$2.073E^{-02}$
4	14.04 - 22.04.2015	499	4	29	9.94	3.5408	$1.804E^{-02}$
8	09.06 - 12.06.2015	441.8	7	27	5.91	3.6124	$1.187E^{-02}$
9	12.06 - 21.06.2015	287.5	7	27	8.91	3.6124	$2.750E^{-02}$
10	30.06 -24.07.2016	834.1	18	17	21.2	3.5848	$2.273E^{-02}$
12	24.08 - 28.08.2015	167.7	7	25	4.8	3.3948	$2.703E^{-02}$
13	03.09 - 04.09.2015	128	13	25	4.28	3.9732	$2.698E^{-02}$
~~14~~	~~27.09 - 01.10.2015~~	~~472.5~~	~~0~~	~~24~~	~~35.9~~	~~2.6112~~	$\cancel{9.329E^{-02}}$
15	19.10 - 08.11.2015	280.5	2	30	12.08	3.4568	$3.994E^{-02}$
19	14.04 - 19.04.2016	396,7	9	19	12.3	2.9348	$3.387E^{-02}$
20	26.04 - 06.05.2016	303.6	3	26	8.6	3.118	$2.913E^{-02}$
22	25.05 - 03.06.2016	145.3	8	22	6.58	3,1648	$4.588E^{-02}$
23	06.06 - 16.06.2016	609	7	29	12.9	3.83	$1.773E^{-02}$
25	05.07 - 28.07.2016	276.1	9	26	11.91	3.6964	$3.741E^{-02}$
26	11.08 - 19.08.2016	857.5	12	23	19.03	3.6592	$1.944E^{-02}$
27	27.09 - 13.10.2016	315	9	29	10.16	4.023	$2.571E^{-02}$
28	18.10 - 21.10.2016	170	2	22	7.88	2.5864	$5.746E^{-02}$
30	05.12 - 09.12.2016	172	0	28	7.97	3.0464	$4.876E^{-02}$

Source: Author's elaboration

The EEOI for 30 voyages is in the range from $1.187E^{-02}$ for voyage 8 to $9.329E^{-02}$ for voyage 14. During the analysis, it has been noted that fuel consumption for voyage 14 definitely deviates from average consumption during the studied period. Due to the fact that it is not possible to confirm that the specified data regarding fuel consumption during the voyage is correct, the authors decided to eliminate voyage 14 from the studies. Given the above, the EEOI is in the range from $1.187E^{-02}$ for voyage 8 to $5.746E^{-02}$ for voyage 28. When compared to other available research (MEPC, 2014, UCLEI, 2015), the values of the EEOI for the analyzed vessel achieve high values i.e. E^{-02}. This situation is due to the fact that when compared with other cargo ships, m_{cargo} of the research subject reaches low values and is in the range of 2.48 t-4.52 t.

Figure 1 presents an attempt to indicate the relation between m_{cargo} and the EEOI for a particular voyage.

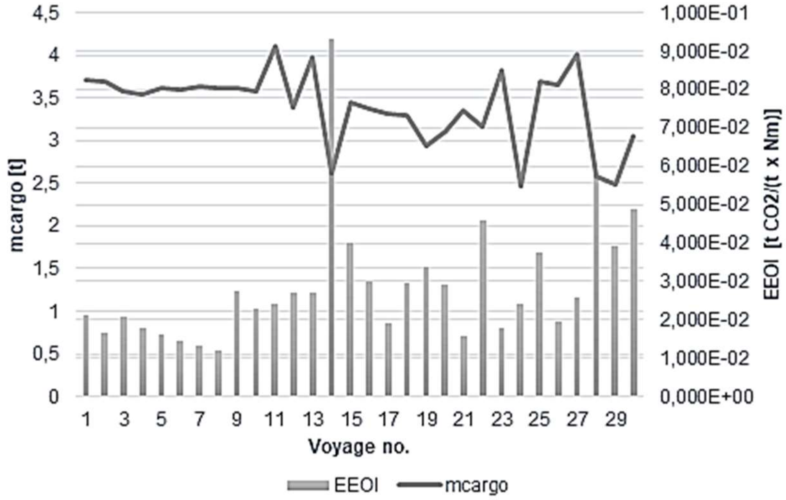

Fig. 1. Relation between m_{cargo} and the EEOI for a particular voyage.
Source: Authors' elaboration.

As it may be noted, there is no direct relation between m_{cargo} and the EEOI. This fact is proven by the analysis of voyages 1-10, where m_{cargo} has the value close to the limit of 0.2 ton, while the indicator values are within the range of 1.32E^{-02}-2.11E^{-02}. Another example proving this assumption in voyage 11 during which m_{cargo} reached the maximum value through all studied voyages i.e. 4.11 t and the EEOI was determined at the level of 2.420E^{-02}.
Figure 2 presents the relations between the distance traveled *D* [Nm] during a particular voyage and the EEOI.

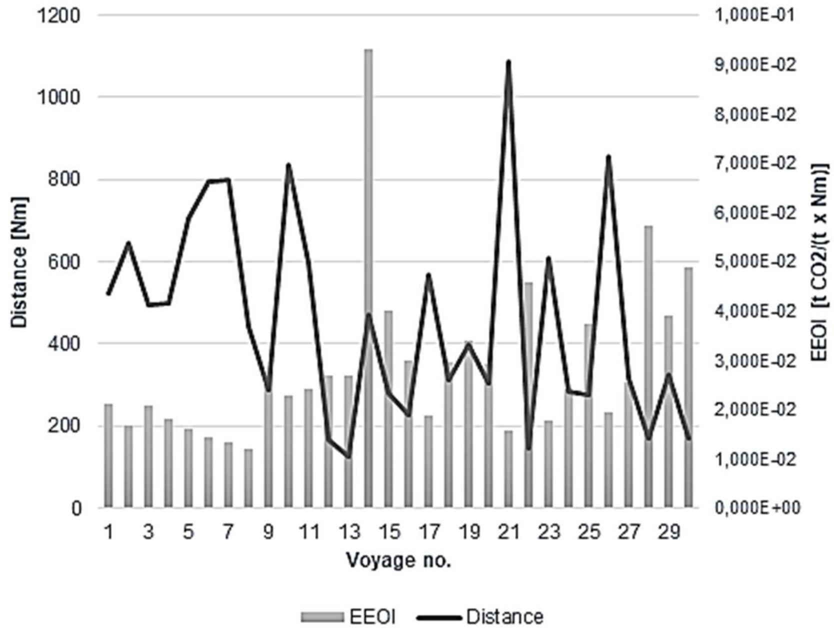

Fig. 2. Relation between distance D and the EEOI during a particular voyage.
Source: Authors' elaboration.

DISCUSSION
The analysis showed that in the case of ship voyage the distance of which exceeds 450 Nm, the EEOI is in the range of 1.325E^{-02}-2.112E^{-02}. For the remaining voyages, shorter than 450 Nm, the indicator values are higher. The authors state there is a relation between short distances and high values of operational efficiency index. This is related to the average vessel speed

during the voyage. The analysis of the ship Log Books proves the fact that in these cases the vessel performed intensive maneuvers with high courses and speed variability. And hence, the fuel consumption significantly increased.

CONCLUSIONS

The above study showed that the standard method to determine the EEOI may not be applied for the research – training vessel. The calculation outcomes indicated significantly higher EEOI when compared with cargo ships. This is mainly caused by m_{cargo} index. Due to the nature of navigation of the research – training vessel, it is unjustified to consider the number of students and researchers as a load. The second factor that affects negatively the EEOI is fuel consumption. It should be noted that vessels of this type rarely travel on the exactly specified routes with a specifically determined speed. As far as the studied vessel is concerned, one may consider the activities of the vessel as maneuvering exercises which were characterized by high variability of speed and courses which in turn resulted in increased fuel consumption. The characteristic of the research of the vessel requires paying attention to maintain navigational and maneuvering parameters with particular regard to keep appropriate, specific speed during measurements instead of being focused on economic fuel management. The authors believe that it is necessary to develop new approach to the EEOI for research ships. In particular, new indicators should be developed or criteria for *performed transport work,* that would be suitable for a particular vessel type, should be indicated. This would enable to optimize the process of ensuring appropriate energy efficiency of the ship in terms of its operation.

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