The effect of early berthing prospects on the energy efficiency operational index in oil tanker vessels

N Acomi¹ and O C Acomi²
¹Constanta Maritime University, 104 Mircea cel Batran Street, 900663, Constanta, Romania
²Robert Gordon University, Garthdee House, Garthdee Road, Aberdeen, AB10 7QB, UK

E-mail: nicoleta.acomi@cmu-edu.eu

Abstract. Marine pollution is one of the main concerns of our society. In order to reduce air pollution produced by ships, the International Maritime Organization has developed technical, operational and management measures. Part of the operational measures refers to CO₂ emissions that contribute to the energy efficiency of the vessel. The difficulty in assessing the energy efficiency of the vessel rests with the diversity of voyage parameters, including quantity of cargo, distance and type of fuel in use. Assessing the energy efficiency of the vessel is thus not a matter of determining the absolute value of the CO₂, but of providing a meaningful construct to enable tracking performance trends over time, for the same ship, a fleet of ships or across the industry. This concept is the Energy Efficiency Operational Index, EEOI. The purpose of this study is to analyse the influence of a well predicted voyage on the EEOI value. The method used consists in a comparative analysis of two situations regarding berthing prospects: the real passage plan and an early prediction that supposes the vessel to arrive on time as required. The results of the study represent a monitoring tool for the ship owners to assess the EEOI from the early stage of designing the berthing prospects.

1. Introduction
Maritime transport is a small contributor to the total volume of CO₂ atmospheric emissions, compared to air, railway or road transport as well as other industries such as manufacturing, construction and electricity production [1]. Based on CO₂ emissions per tonne of cargo transported one mile, shipping is recognised as being the most efficient form of commercial transport. However, the International Maritime Organization (IMO) has estimated shipping’s contribution to the world's total greenhouse gas emissions at around 3% of the total global CO₂ emissions, as per figure 1.

Consequently, IMO has elaborated guidelines and regulations, to reduce air emissions and increase fuel efficiency. The measures for energy efficiency [2] comprise:

- The Energy Efficiency Design Index (EEDI), mandatory for new ships;
- The Ship Energy Efficiency Management Plan (SEEMP) for all ships with the adoption of amendments to MARPOL Annex VI;
- The Energy Efficiency Operational Index (EEOI) as a monitoring tool that enables operators to measure the fuel efficiency of a ship in operation and to estimate the effect of different changes in operation, such as the improved voyage planning or more frequent propeller
cleaning, or the introduction of technical measures such as the waste heat recovery systems or a new propeller.

The first two measures, technical and management related, are mandatory while the last, the EEOI, is recommended as an approach for shipping companies to assess the fleet efficiency performance.

The use of EEOI as operational measure to reduce the CO$_2$ emissions and as means of estimating emissions on board vessels [3,4,5] were detailed in the Guidelines for voluntary use of the ship energy efficiency operational indicator, in 2009 [6]. These guidelines provide an example of monitoring the efficiency of a ship in operation, by dividing the CO$_2$, which is a function of the consumed fuel, to the transport work, which is the cargo mass in tonnes multiplied by the total distance sailed in nautical miles.

Due to the main purpose of the vessel, to carry goods for different distances, the instrument for achieving the air emissions is not only a quantitative measure; it represents the amount of emissions related to the vessel's performance.

![Figure 1. Emissions of CO$_2$ from shipping compared to global total emissions [1].](image)

In 2013, the IMO and the World Maritime University (WMU) have developed a model course for training the personnel and promoting the energy efficient operation of ships [7]. This training course has a global dimension addressing several topics and aiming at providing a set of knowledge in the implementation of energy efficiency polices. It specifies that the current state of knowledge is limited and under development and the topics should be accordingly discussed and debated during training periods.

The effective co-ordination is indicated as a company policy for reducing emissions from ships and increasing the energy efficiency [7]. Transport efficiency is affected by the time spent in port or during port related operations such as: tug operators, bunker suppliers or stevedores. To minimise the time spent in port it is recommended that the ships operators use the Vessel Traffic Services and consider the cargo handling, berthing and mooring.

Based on the just-in-time concept, the following presents the comparative analysis of two situations regarding berthing prospects. The first case is the real passage plan developed on board an oil/chemical tanker vessel. For this case study, the voyages carried out between July and September 2013 were analysed. The second prospect is an estimation of the EEOI value considering that the early prediction minimises the number of days at anchor by proceeding with minimum economic speed required to arrive on time as required.

2. EEOI calculation for an oil tanker vessel
The voyage parameters influencing the EEOI value and the associated energy efficiency of the vessel include the voyage legs, types of marine fuel for different legs, days at anchors, and port and idle periods. The technical and operational characteristics of the vessel's consumers, main engine, diesel
generators, boiler and inert gas generator, their daily consumption, as well as the types of marine fuels, are considered as per the Engine Log Book and included in the analysis.

The vessel considered in this case study is an Aframax Oil Tanker, 107157 DWT, equipped with:

- Main Engine (ME) MAN B&W 6S60MC-C 13,560 kW at 105 RPM;
- Three Daihatsu 6DK20 Diesel Generator (DG) Sets of 960 kW and 900 RPM;
- Auxiliary Boilers (AB) Aalborg Mission TM OL of 18 bar working pressure and 25 t/h steam capacity.

The analysis covers one complete voyage, figure 2, carried out during the third quarter of 2013. The real EEOI was calculated for this voyage. In this context, “voyage” is considered the period between the departure from the previous loading port, Tetney (UK), to the departure from the discharge port Sabine (USA).

![Figure 2](image)

**Figure 2.** (a) Tetney, UK to Kerch, Ukraine, 3/07/2013 – 25/07/2013
(b) Kerch, Ukraine to Sabine USA, 25/07/2013 – 31/08/2013.

The EEOI is calculated using the following formula (1), where a smaller EEOI value means a more energy efficient ship:

$$EEOI = \frac{\sum_{j} FC_{ij} \times C_{Fj}}{m_{cargo} \times D}$$

(1)

where:
- $j$ - fuel type;
- $i$ - voyage number;
- $FC_{ij}$ - mass of consumed fuel $j$ at voyage $i$;
- $C_{Fj}$ - fuel mass to CO$_2$ mass, conversion factor for fuel $j$;
- $m_{cargo}$ - cargo carried (tonnes);
- $D$ - distance (in nautical miles) corresponding to the cargo carried.

The type of fuel used during the voyage was Heavy Fuel Oil (HFO) ISO 8217 grades RME through RMK, as stated in the Charter Party Agreement, subject to international and local regulations, having Carbon Content = 0.85 and Conversion Factor $CF = 3.114400$ (t-CO$_2$/t-Fuel).

The operational characteristics of consumers, i.e. main engine, diesel generators, boiler, their daily consumption, as well as the type of marine fuels, the voyage legs and the speed, are values extracted from the Engine, Nautical and Cargo Log Book, Table 1. The data calculation sheet developed by authors, tables 1 and 2 calculate in the first situation the actual EEOI value based on the fuel consumption during the voyage legs, and the carbon content of fuel.
Table 1. Operational characteristics of the vessel’s consumers.

| Scenario                        | Average speed [knots] |
|---------------------------------|-----------------------|
|                                 |                      |
| Daily consumption speed-dependent |                      |
| ME Loaded [mt]                  | 35                    | 17                     |
| ME Ballast [mt]                 | 30                    | 15.5                   |
| DG at sea [mt]                  | 3                     | 3                      |
| Boiler at sea [mt]              | 0                     | 2                      |
| Daily consumption NON speed-dependent |                |
| ME maneuver [mt]                | 14                    |
| DG idle [mt]                    | 3                     |
| DG maneuver [mt]                | 4                     |
| DG discharge [mt]               | 5                     |
| AB idle [mt]                    | 3                     |
| AB discharge [mt]               | 40                    |
| Cargo heating [mt]              | 11                    |

3. Comparative analysis of the two situations of berthing prospects
The two situations stated above, real and hypothetical imply a change in the speed of the vessel in the sense of decreasing it to a minimum, in order to avoid arriving early according to just-in-time concept.

Figure 3. Program interface.
Proceeding on passage with minimum economic speed lowers the fuel consumption and emphasises the influence of the speed of the vessel over the CO\textsubscript{2} emissions and over the energy efficiency of the vessel.

**Table 2. Calculation of EEOI for the two Berthing Prospects.**

| Berthing Prospects          | 1st prospect for speed 13.5 knots | 2nd prospect for reduced speed |
|-----------------------------|-----------------------------------|--------------------------------|
| Fuel consumption [T]        | 1863.2                            | 1699.5                         |
| CO\textsubscript{2}/1000000 [T] | 5803                              | 5293                           |
| Cargo [T]                   | 98232                             | 98232                          |
| Distance Loaded [Nm]        | 6431                              | 6431                           |
| Distance Ballast [Nm]       | 3713                              | 3713                           |
| EEOI                        | 9.19                              | 8.38                           |
| EEOI Reduction %            |                                    | 8.79                           |

For validation of results, the voyage parameters have been used with the commercial software developed by Totem Plus Company (figure 4) that calculates the EEOI and the average EEOI based on the type of fuel, distances when loaded/ballast, and the quantity of cargo.

The fuel consumptions for the first berthing prospect have been reported as average for the full length of the voyage, broken down for each machinery in each specific voyage leg, while for the early berthing prospect situation the consumptions have been estimated based on the vessel experience records. The value resulted for the EEOI is 9.19, corresponding to real voyage and is equal to the value resulted from the use of EEOI Software calculator, 9.2 (Figure 4).

The second prediction is a hypothetical situation of an early berthing that supposes to minimize the number of days at anchor and to proceed with the minimum speed required in order to achieve berthing directly on arrival. The two values of EEOI obtained for each of the two situations are then being analysed from environmental protection and economic impact point of view.
Optimization of the voyage parameter analysed in this case study had initially concerned reduction of CO$_2$ emissions, and the achieved EEOI values were 9.19 for the 1st prospect and 8.38 for the 2nd prediction. Besides this, it can be noticed the difference in fuel consumption which influences the total cost of the voyage. The cost of marine fuel [9] used for the real voyage, Heavy Fuel Oil, compared to the cost for performing the same voyage with most economic speed adjusted according to the early berthing prospects, are presented in table 3.

Table 3. Cost calculation.

| Type of fuel              | Cost [USD/tonnes] | Fuel cost [USD] 1st case-real voyage | Fuel cost [USD] 2nd Berthing prospect |
|--------------------------|-------------------|--------------------------------------|---------------------------------------|
| Heavy Fuel Oil (HFO)     | 171.00            | 318607.00                            | 290615.00                             |

The cost saving resulted from reducing the fuel consumption associated to adjusted speed is 27992.00 USD per studied voyage.

4. Conclusions
The EEOI provides the ship-owners with useful information on a ship’s performance with regard to fuel efficiency and also cost optimization. The comparative analysis of the two voyage situations emphasizes the difference in CO$_2$ emissions, which is materialized into 8.79% EEOI reduction for the case where an accurate early berthing prospect was available, against the real voyage. Both prospects being related to the same voyage, the same distance loaded / ballast, quantity of cargo and also the same type of cargo, only variable is represented by the fuel consumption, then the same reduction of 8.79% is reflected into the cost of the marine fuel.

Acknowledgements
The acknowledgement to the Totem Plus Company for their kindness in allowing us to use the EEOI Calculator Free Software.

References
[1] International Maritime Organization 2009 MEPC 59/INF.10 Second IMO GHG Study.
[2] International Maritime Organization 2011 MEPC 62 Amendments to the annex of the protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978 relating thereto.
[3] Figari M, D’Amico M and Gaggero P 2012 Evaluation of ship efficiency indexes Sustainable Maritime and Exploitation and Sea Resources 1 621-627.
[4] Fong-Yuan M 2014 Analysis of energy efficiency operational indicator of bulk carrier operational data using grey relation method Journal of Oceanography and Marine Science 5(4) 30-36.
[5] International Maritime Organization 2011 Agenda item 9/a Emissions from fuel used for international aviation and maritime transport, Technical and operational measures to improve the energy efficiency of international shipping and assessment of their effect on future emissions.
[6] International Maritime Organization 2009 MEPC 1/Circ.684 Guidelines for voluntary use of the ship energy efficiency operational indicator, EEOI.
[7] WMU-IMO 2013 Training course on Energy Efficient Operation of Ships. International Maritime Organization and World Maritime University.
[8] www.totemplus.com – EEOI free calculator.
[9] http://www.insee.fr/en, accessed February 2016.