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

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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 CO_2 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 CO_2, 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 CO_2 atmospheric emissions, compared to air, railway or road transport as well as other industries such as manufacturing, construction and electricity production [1]. Based on CO_2 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 CO_2 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.

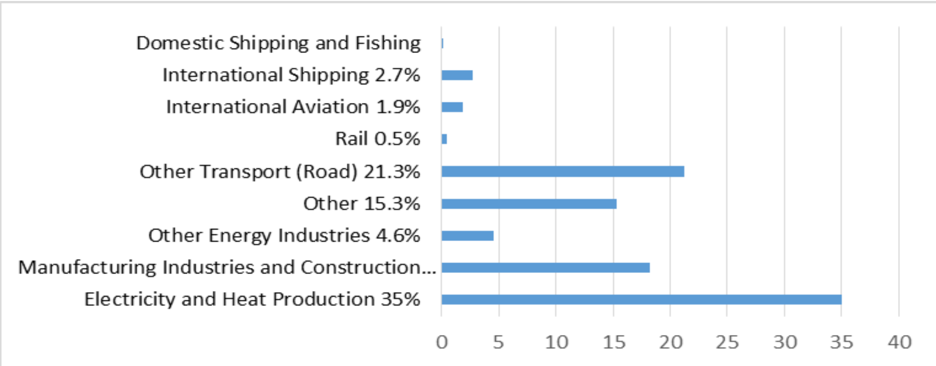

Figure 1. Emissions of CO_2 from shipping compared to global total emissions [1].

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).

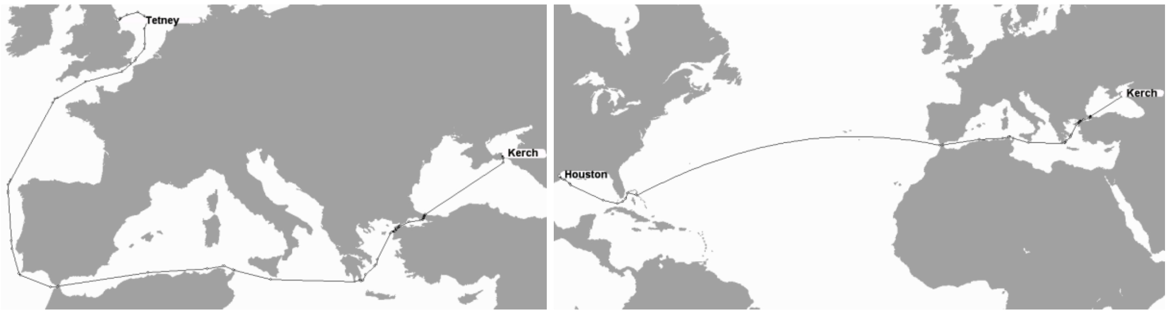

Figure 2. (a) Tetney, UK to Kerch, Ukraine, 3/07/2013 – 25/07/2013
(b) Kerch, Ukraine to Sabine USA, 25/07/2013 – 31/08/2013.

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

$$EEOI = \frac{\sum_j FC_j \times C_{Fj}}{m_{c\arg o} \times D} \tag{1}$$

where:

- j - fuel type;
- i - voyage number;
- FC_{ij} - mass of consumed fuel j at voyage i;
- CF_j - 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.

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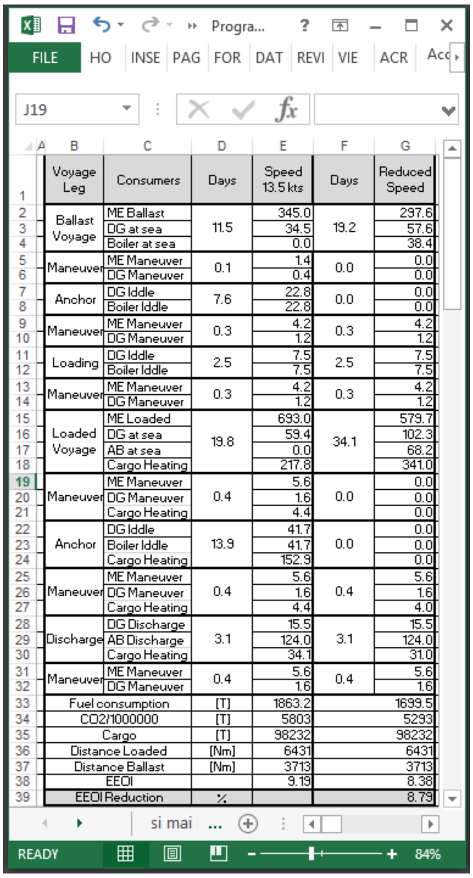
Table 1. Operational characteristics of the vessel's consumers.

Scenario		Average speed [knots]	
		13.5	Reduced
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.



Voyage Leg	Consumers	Days	Speed 13.5 kts	Days	Reduced Speed
Ballast Voyage	ME Ballast	11.5	345.0	19.2	297.6
	DG at sea		34.5		57.6
	Boiler at sea		0.0		38.4
Maneuver	ME Maneuver	0.1	1.4	0.0	0.0
	DG Maneuver		0.4		0.0
Anchor	DG Iddle	7.6	22.8	0.0	0.0
	Boiler Iddle		22.8		0.0
Maneuver	ME Maneuver	0.3	4.2	0.3	4.2
	DG Maneuver		1.2		1.2
Loading	DG Iddle	2.5	7.5	2.5	7.5
	Boiler Iddle		7.5		7.5
Maneuver	ME Maneuver	0.3	4.2	0.3	4.2
	DG Maneuver		1.2		1.2
Loaded Voyage	ME Loaded	19.8	693.0	34.1	579.7
	DG at sea		59.4		102.3
	AB at sea		0.0		68.2
	Cargo Heating		217.8		341.0
Maneuver	ME Maneuver	0.4	5.6	0.0	0.0
	DG Maneuver		1.6		0.0
	Cargo Heating		4.4		0.0
Anchor	DG Iddle	13.9	41.7	0.0	0.0
	Boiler Iddle		41.7		0.0
	Cargo Heating		152.9		0.0
Maneuver	ME Maneuver	0.4	5.6	0.4	5.6
	DG Maneuver		1.6		1.6
	Cargo Heating		4.4		4.0
Discharge	DG Discharge	3.1	15.5	3.1	15.5
	AB Discharge		124.0		124.0
	Cargo Heating		34.1		31.0
Maneuver	ME Maneuver	0.4	5.6	0.4	5.6
	DG Maneuver		1.6		1.6
Fuel consumption		[T]	1863.2		1699.5
CO2/1000000		[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

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_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_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.

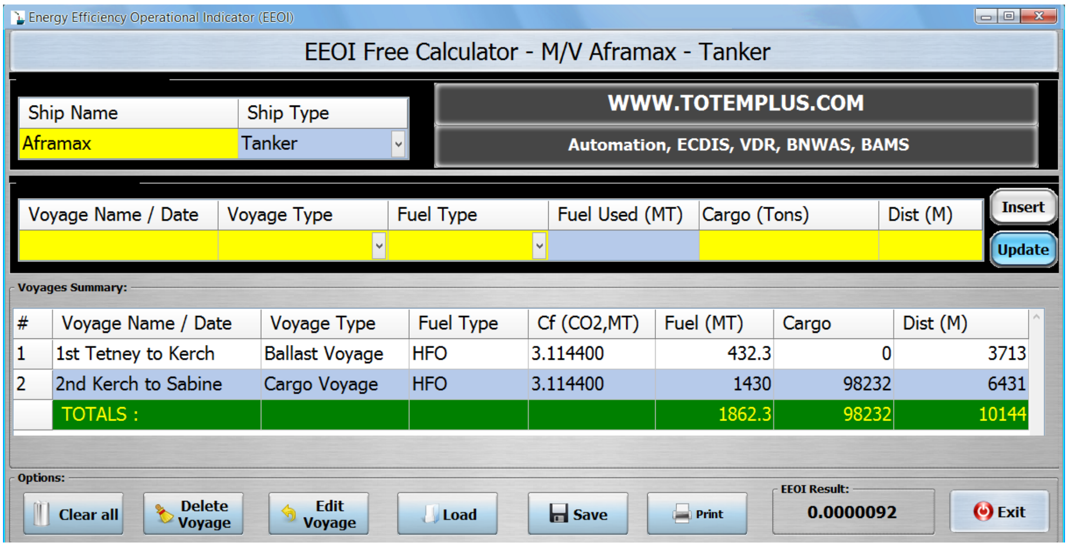


Figure 4. The interface of the EEOI Software calculator [8].

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

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