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An Alternative Energy Efficiency Index Offer to Reduce CO_2 Emissions from Ships: Fleet Energy Efficiency Management Index

Görkem Kökkülünk[1] and Adnan Parlak[2]

Abstract

The Energy Efficiency Operational Index (EEOI) is the novel important challenge that the shipping companies have to face associated with the Ship Energy Efficiency Management Plan (SEEMP) in accordance with the International Maritime Organization (IMO) MARPOL (International Convention for the Prevention of Pollution from Ships) Annex VI regulations. The EEOI obtains a quantitative indicator of energy efficiency of a ship in operation, hence it might be considered as the primary monitoring tool for ship efficiency performance and to optimize the performance of the ship.

In this study, changing of the ship EEOI is investigated in case of fully and partial laden of the sample ship named M/V Ince Anadolu. It is revealed that operating in fully laden of ships have an importance as much as efficient operation of energy consuming systems to reduce CO2 emissions from ships. Moreover, it is obvious that the fleet management policy of companies has been monitoring as much as one ship. In this context, the novel term "Fleet Energy Efficiency Management Index" (FEEMI) is defined to measure the energy efficiency management ability of the companies.

Keywords: Ship, Fleet, Energy, Efficiency, EEOI

1 Introduction

The Energy Efficiency Operational Index (EEOI) which has been an evaluation criterion for CO_2 emissions with transportation capacity is one of the newly significant challenges that the shipping companies have to face associated with the Ship Energy Efficiency Management Plan (SEEMP) in accordance with the International Maritime Organization (IMO) MARPOL Annex VI regulations.

The EEOI which represents the overall trading pattern of the vessel, obtain a quantitative indicator of energy efficiency of a ship and/or fleet in operation, thus, it might be

[1]Yildiz Technical University, Naval Arch. & Maritime Faculty, Marine Engineering Department 34349 Istanbul/Turkey.
[2]Yildiz Technical University, Head of Marine Engineering Department 34349 Istanbul/Turkey.

considered as the primary monitoring tool as described in SEEMP which provides for monitoring ship and fleet efficiency performance and to optimize the performance of the ship (SEEMP, 2012, EEOI, 2009).

There are many studies about ship energy efficiency and EEOI. Keshun et al. (2014) studied the simulation and analysis of the ship energy efficiency operation index that is established by taking a 46000 DWT oil tanker as an example. Yang et al. (2013) investigated the adaptability of marine dual fuel engine on the new regulations of IMO MARPOL and the prospect of marine dual fuel engine application based on emission and energy efficiency. Coraddu et al. (2013) showed ship energy assessment by numerical simulation to estimate vessel fuel consumption in a real case study. Tzannatos et al. (2013) investigated the energy efficiency of domestic passenger shipping for assessing the influence of fuel expenditure upon the overall cost of the supplied services in Greece. Johnson et al. (2013) discussed the question that the ship energy efficiency management plan will reduce CO_2 emissions and compared with ISO 50001 and the ISM code. Baldi (2013) investigated a synthesis conducted over two and a half years on the subject of improving ship energy efficiency through a systems perspective. Xing et al. (2013) studied the operational energy efficiency for inland river ships with regards to greenhouse gas emissions and compares them with the performance of seagoing ships. Schmid (2007) presented efficient propulsion for seagoing vessels to consume minimum amount of fuel to achieve a defined ship speed and to generate minimum emissions. Hasselaar (2009) investigated the ship service performance to reduce fuel consumption through propeller-hull interaction. Mohr et al. (2011) searched the engine performance optimization by permanent use of holistic expert condition monitoring system. Kane (2013) presented a more fuel efficient tonnage and emission reduction of Ocean Going Vessels through blasting of hulls and Propeller Performance Monitoring.

In the other respect as the slow steaming, Woo et al. (2014) investigated the effects of slow steaming on the environmental performance in liner shipping with respect to voyage speed, the amount of CO_2 emissions and operating costs on a loop. Smith (2012) studied the influence and sensitivity of speed and technical energy efficiency to owner's profits and the implications for the management of shipping's carbon emissions. Lindstad et al. (2011) analyzed the potential for reducing CO_2 emissions and greenhouse gas emissions and cost by shipping at lower speeds. Chang et al. (2013) discussed the energy conservation for international dry bulk carriers to examine emissions under economic speed and via vessel speed reductions of 10%, 20%, and 30%. Chang et al. (2014) also investigated evaluating the effects of speed that minimize costs and reduce the impact of shipping on the environment. Corbett et al. (2009) investigated the effectiveness and costs of speed reductions on emissions from international shipping. Norlund et al. (2013) examined how to reduce emissions from supply vessel operations by optimizing sailing speed in the supply vessel planning in the upstream supply chain to offshore installations.

In this paper, it has been focused on the energy efficiency operation index calculation of the Ince Shipping Company fleet ship named M/V Ince Anadolu by means of real data and the suggestions for reducing the EEOI value

2 Method for calculation of EEOI and FEEMI

It is obviously that the base method is to reduce the fuel consumption to decrease the Green House Gases (GHG) and pollutant emissions from ships. Also it has been referred on the introduction section that reducing speed or slow steaming is the way to reduce these emissions with regards to reduce fuel consumption. Furthermore, beneficial work which is the most relevant to transportation work with the minimum fuel consumption.

In the IMO MARPOL Annex VI Marine Environment Protection Committee has been offered guidelines that describe the beneficial work to reduce emissions. Thus, EEOI which is the suggestion of IMO could be considered as the primary monitoring tool to calculate the beneficial work done by ships (SEEMP, 2012, EEOI, 2009).

In its easily form the EEOI is defined as the ratio of mass of CO_2 emitted per unit of transport work (SEEMP, 2012, EEOI, 2009):

Indicator = MCO_2/(transport work)

Also it is the simplest way to understand the EEOI calculations (Mundt, 2011);

$$EEOI = \frac{\text{Fuel}_{consumed} \times \text{C}_{carbon}}{\text{Cargo}_{transported} \times \text{Distance}_{sailed}} \tag{1}$$

EEOI is an important index that could be an opportunity to control and understand the SEEMP and has revealed how the SEEMP is a realistic and substantial. With regards to calculating the EEOI, ship owners would have a handsome profits in a long terms.

The basic expression for EEOI for a voyage is defined as in Guideline of MEPC.1/Circ.684 (SEEMP, 2012, EEOI, 2009):

$$EEOI = \frac{\sum_j FC_j \times C_{Fj}}{m_{\text{cargo}} \times D} \tag{2}$$

Where average of the indicator for a period or for a number of voyages is obtained, the Indicator is calculated as (SEEMP, 2012, EEOI, 2009):

$$EEOI_{average} = \frac{\sum_i \sum_j \left(FC_{ij} \times C_{Fj}\right)}{\sum_i \left(m_{\text{cargo}} \times D_i\right)} \tag{3}$$

Where j is the fuel type, i is the voyage number, FC_{ij} is the mass of consumed fuel j at voyage i, CF_j is the fuel mass to CO_2 mass conversion factor for fuel j, m_{cargo} is cargo carried and D is the distance in nautical miles corresponding to the cargo carried or work done.

Moreover, C_F is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content. The value of C_F is as follows as suggested in Guideline of MEPC.1/Circ.684 (SEEMP, 2012, EEOI, 2009);

Table 1: C_F Values of the Dıfferent Type of Fuels

Type of Fuels	Reference	Carbon Content	C_F t-CO_2/t-Fuel
Diesel/Gas Oil	ISO 8217 DMX-DMC	0.875	3.206
LFO	ISO 8217 RMD	0.86	3.151040
HFO	ISO 8217 RMK	0.85	3.1144
LPG	Propane-Butane	0.819-0.827	3.00-3.03
LNG	-	0.75	2.750

2.1 Fleet Energy Efficiency Management Index (FEEMI)

FEEMI is a novel defined term that describe the company management success based on operating the ships with respect to maximum load capacity. The indicator is calculated as;

$$FEEMI = \frac{EEOI_{average}}{n} = \frac{\sum_i \sum_j \left(FC_{ij} \times C_{Fj}\right)}{n \sum_i \left(m_{Cargo} \times D_i\right)} \tag{4}$$

Where n is the number of the ships in the fleet.
FEEMI indicates operating capacity of all the ships in the fleet in accordance with energy efficiency. Even though the EEOI measures the one ship energy consuming systems management ability, the FEEMI measures the company management operating ability of the fleet with regards to energy efficiency.

3 Calculations for Case Study

The specifications of the case studied ship M/V Ince Anadolu is illustrated in Table 2.

Table 2: Specification of the M/V Ince Anadolu

SHIP NAME	M/V INCE ANADOLU
IMO No / Tugs No	9527271 / 1721
Built Date	MARCH 2009
D.Weight (MT) Sum/Tro/FW	76619/78579/76582
Gross Ton	39737
Net Ton	25754
Main Engine (M/E)	Hitachi MAN B&W 6S60MC
Rated Power of M/E	10320 kW (14031 BHP)
Main Diesel Generator Engine	455 kW x 3 Set Yanmar 6EY18AL

Table 3 illustrates the Voyage and Passage details of M/V Ince Anadolu. The average EEOI of voyages are 6.9, 14.9, 9.3, 8.0, 20.7, 9.4, 8.5 (x10^{-6} tonne-CO_2/tonne-mile), respectively. The voyage 5 has the highest EEOI value due to unladen sailing of the ship. The average of all voyages are 11.1 $x10^{-6}$ tonne-CO_2/tonne-mile. When examining the Voyage 2 and 5, it can be seen that transport work ($Cargo_{transported}$ x $Distance_{sailed}$) is less than the other voyages. Eventually, Voyage 2 and 5 are above the average Voyage EEOI.

Table 3: Passage details of M/V Ince Anadolu

Passage No	Voyage No	Departure Port	Next Departure Port	EEOI, $x10^{-6}$ t-CO_2/t-mile	Voyage EEOI, $x10^{-6}$ t-CO_2/t-mile	Loading Percentage, %
1	1	YUZHNY	CONSTANTA	-	6.9	51%
2	1	CONSTANTA	ISTANBUL	14.6		
3	1	ISTANBUL	SUEZ	7.3		
4	1	SUEZ	UMM QASR	6.9		
5	2	UMM QASR	FUJAIRAH	7.8	14.9	43%
6	2	FUJAIRAH	MESAIEED	7.8		
7	3	MESAIEED	FUJAIRAH	8.1	9.3	25%
8	3	FUJAIRAH	WALLAROO	14.2		
9	3	WALLAROO	PT. LINCOLN	14.4		
10	3	PT.LINCOLN	BAND.ABBAS	8.7		
11	4	BAND.ABBAS	MINA SAQR	8.8	8.0	40%
12	4	MINA SAQR	JAIGARH	8.6		
13	5	JAIGARH	SUEZ	10.1	20.7	44%
14	5	SUEZ	KUMKALE	10.4		
15	5	KUMKALE	ISTANBUL	10.5		
16	5	ISTANBUL	YUZHNY	10.6		
17	5	YUZHNY	ISTANBUL	10.5		
18	5	ISTANBUL	KUMKAPI	10.5		
19	5	KUMKAPI	SUEZ	10.2		
20	5	SUEZ	JEDDAH	10.2		
21	5	JEDDAH	YANBU	10.4		
22	6	YANBU	SUEZ	10.5	9.4	32%
23	6	SUEZ	ISTANBUL	10.8		
24	6	ISTANBUL	KOSTENCE	10.8		
25	6	KOSTENCE	ISTANBUL	10.8		
26	6	ISTANBUL	SUEZ	10.7		
27	6	SUEZ	KARACHI	10.3		
28	7	KARACHI	SUEZ	11.0	8.5	51%
29	7	SUEZ	ISTANBUL	11.3		
30	7	ISTANBUL	NIKOLAEV	11.3		
31	7	NIKOLAEV	NOVOROSSIYK	11.2		
32	7	NOVOROSSIYK	ISTANBUL	11.0		
33	7	ISTANBUL	SUEZ	10.8		
34	7	SUEZ	FUJAIRAH	9.9		

4 Results and Discussion

In this study, change of M/V Ince Anadolu EEOI value has been investigated in the event of fully and partial laden. Also, the novel term "Fleet Energy Efficiency Management Index" (FEEMI) which is defined to measure the energy efficiency management ability of the companies has been calculated.

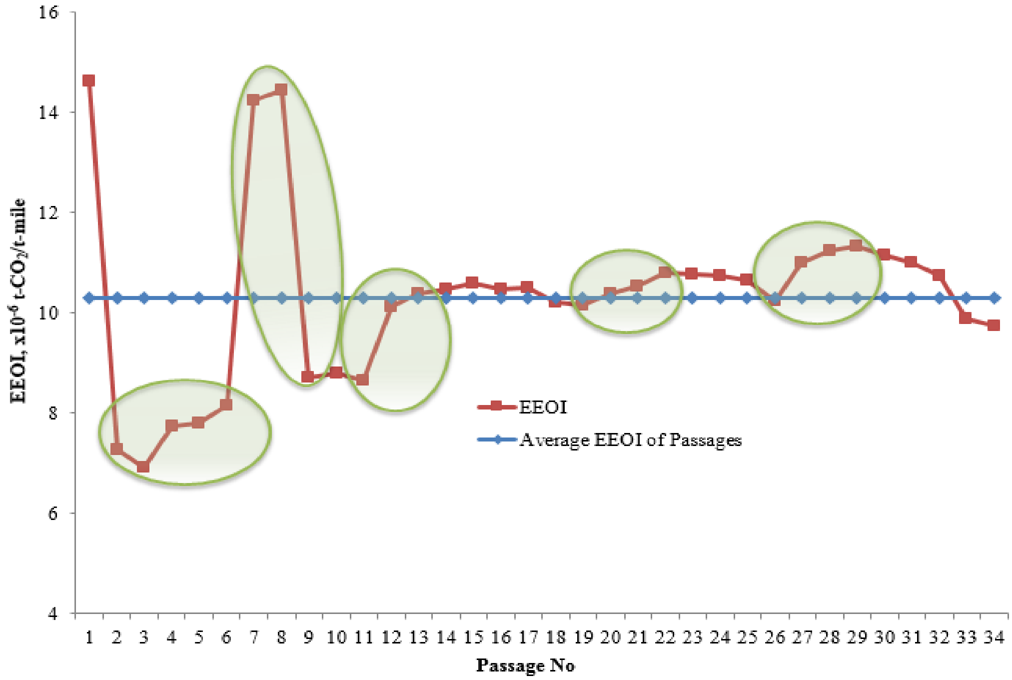

Figure 1: Assessment of EEOI calculation of M/V Ince Anadolu.

Figure 1 shows the assessment of EEOI of the ship named M/V Ince Anadolu through 34 passages, 7 voyages. The average value of passage EEOI is 10.3 x10^{-6} tonne-CO_2/tonne-mile. Since the passage 7-8 inside the voyage 3 has no transport work, the EEOI values are suddenly increase with a huge amount. Passage 22-23 inside the voyage 6 and passage 28-29-30 inside the voyage 7 are slightly increase because of no transport work.

Table 4: Passage details of M/V Ince Anadolu

Passage No	Voyage No	Departure Port	Next Departure Port	EEOI
13	5	JAIGARH	SUEZ	10.1
14	5	SUEZ	KUMKALE	10.4
15	5	KUMKALE	ISTANBUL	10.5
16	5	ISTANBUL	YUZHNY	10.6
17	5	YUZHNY	ISTANBUL	10.5
18	5	ISTANBUL	KUMKAPI	10.5
19	5	KUMKAPI	SUEZ	10.2
20	5	SUEZ	JEDDAH	10.2
21	5	JEDDAH	YANBU	10.4

Table 4 illustrates the passages of Voyage 5. It can be seen that No:5 Voyage is the highest one in comparison to the others and is also caused to increase the average EEOI value. The reason of increasing the average EEOI can be explained that the ship was sailing 2063 and 4083 nautical mile as laden and unladen position, respectively. In other word, the laden sailing distance is two times less than unladen sailing distance. When averaging all the passages of the Voyage 5, the loading percentage is calculated as 44%. Similarly, CO_2 emission ratio between Jaigarh and Yuzhny (Passage No: 13,14,15,16) is calculated as 41.5% of all the Voyage 5.

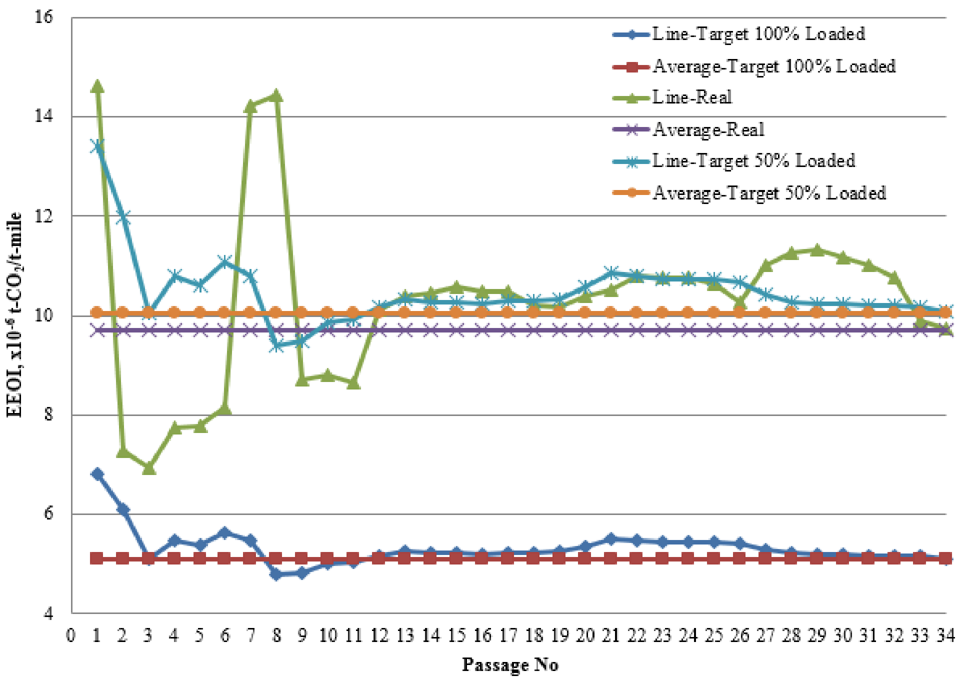

Figure 2: EEOI calculations for different loading of M/V Ince Anadolu.

Figure 2 shows the EEOI calculations for different loading position of M/V Ince Anadolu. The scenario 1 is fully loaded (Line Target 100%) and the scenario 2 is 50% loaded (Line 50% Load Target). As can be seen from figure, the EEOI values decreases with the increase of load capacity due to increasing transport works.

Table 5: Average EEOI values of the Fleet

Classification	**Ships on Fleet**	**$EEOI_{average}$, x10^{-6} tonne CO_2/ton-mile**
A	M/V İNCE KARADENİZ M/V İNCE KASTAMONU M/V İNCE AKDENİZ	7.7 7.4 8.1
B	M/V İNCE PACIFIC M/V İNCE ATLANTIC	10.2 7.2
C	M/V İNCE HAMBURG	11.0
D	M/V İNCE ILGAZ M/V İNCE ANADOLU	7.8 9.7
E	M/V İNCE FORTUNE M/V İNCE EGE	9.1 10.5
F	M/V İNCE ANKARA	7.2
G	M/V İNCE BEYLERBEYİ	9.2
H	M/V İNCE İNEBOLU	7.3
FEEMI		8.646

Table 5 illustrates the average EEOI values of the fleet and fleet energy efficiency management index (FEEMI). The classifications are done according to the sister ships. The FEEMI value is 8.646 x10^{-6} t-CO_2/t-mile and 6 ships are above the average of the FEEMI. It means that 6 ships rearrange the transport work capacities or fuel consumptions.

5 Conclusion

The ship energy efficiency has a vital role in terms of reduction of CO_2 emissions released into the environment. However, commercial ship management (means in the formula; transport work) has also substantial role besides efficient ship design and engine management to reduce the carbon emissions.

In the case study, the EEOI values of the ship named M/V Ince Anadolu was calculated and the FEEMI values of the fleet was demonstrated. The average EEOI of voyages are 6.9, 14.9, 9.3, 8.0, 20.7, 9.4, 8.5 (x10^{-6} tonne-CO_2/tonne-mile), respectively. The voyage 5 has the highest EEOI value due to unladen sailing of the ship. The average of all voyages are 11.1 x10^{-6} tonne-CO_2/tonne-mile. When examining the Voyage 2 and 5, it can be seen that transport work ($Cargo_{transported}$ x $Distance_{sailed}$) is less than the other voyages. Eventually, Voyage 2 and 5 are above the average Voyage EEOI. CO_2 emission ratio between Jaigarh and Yuzhny (Passage No: 13,14,15,16) is calculated as 41.5% of all the Voyage 5. This result shows that any efficient technology improvements does not become as effective as sailing fully loaded capacity to reduce EEOI and FEEMI. Thus, the ships in the world trade have to be classified as in the machines of our life refrigerators, laundry machines with respect to EEOI. Also ship management companies have to be classified according to the efficient management index (FEEMI).

Consequently, laden sailing has a significant role in the calculation of the EEOI. Namely, the main reason for the increase of emissions is to operate the ship with a low capacity. Since ships are consistently operating in different loads and lines, factual assessments cannot be done with only EEOI. Furthermore, precautions which is for reducing EEOI cannot be seen from the EEOI values. However, evaluation of the ship and fleet performances will be more meaningful, when EEOI and FEEMI are used together.

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