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Goal Setting of EEOI for Chemical Tankers by Monte Carlo Simulation

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Abstract

In accordance with the current regulations, the companies have to investigate the suitability of the applied operational measures; to assess the available solutions for the energy efficiency improvement of their fleet; and produce more suitable operational measures or revise their already applied measures. For this purpose, there is need to have a SEEMP and achieve EEOI targets. In this paper, a method for the prediction of the annual performance of the energy efficiency for a company's fleet, based on Monte Carlo Simulation will be presented. As a case study, the method will be applied on a chemical tanker fleet. Recorded voyage data, including EEOI values, cargo type and quantity, mileage covered, speed profiles, fuel types etc., will be used. Conclusions on the feasibility, usability, reliability as well as suggestions for further development of the method will be included.

Keywords

Energy Efficiency, EEOI, Goal Setting

1. Introduction

Globalisation is one of the most popular terms in terms of economy. One of the most important parts of the globalisation is that transportation and maritime transportation has the biggest share of transportation cake with its 89.6% and 70.1% shares of global trade in volume and value respectively (Rodrigue et al., 2013). The maritime sector among other transportation modes is defined by Kurt (2014) as the most globalised and good connector for the majority of international trade. This globalised sector has great growth potential, but subject to this growth, the energy consumption and greenhouse gas emissions from ships can cascade. The concerns in maritime sector about increasing gas emissions have begun consideration of possible measures to reduce gas emissions from ships and to achieve stabilisation in global temperature by meeting required emission targets.

The third IMO GHG study (Smith et al., 2014) indicates that the emitted CO2 from international shipping was 2.2% of the global CO2 emission in 2012. Although the marine shipping is the cleanest transportation mode when compared to other modes, gas emissions from international shipping may increase by a factor of 2 or 3 by 2050 as parallel to the growth in shipping sector if no action is taken. One of the adopted measures is EEOI which gives chance to shipping management companies and ship owner to analyze gas emissions from ships during voyages. In the scope of EEOI, the goal setting is important step of the SEEMP to provide more energy efficient fleet and ship management.

In this paper, EEOI based targets of the future years are simulated by using calculated EEOI scores with the aid of collected data from ships in appropriate format. The simplest form of the EEOI is defined as the ratio of mass of CO2 emitted per unit of transport work (MEPC, 2009). The aim of this study is to propose a method to set EEOI goal due to past voyages' EEOI values in order to achieve the limitation or reduction of GHG emissions from ships in operation, and to show the results of applied method for a ship..

2. The SEEMP Structure and the Calculation of EEOI

According to IMO, The Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) which were adopted amendments to MARPOL Annex VI. With the adoption of the amendments, the EEDI was obligated for new ships and the SEEMP for all ships which are 400 gross tonnages and above. While the EEDI is based on performance and is calculated as in grams of carbon dioxide (CO2) per ship's capacity mile by a formula based on the technical design parameters for a given ship, the SEEMP is an operational based mechanism that was established for a company and/or a ship to improve the energy efficiency of a ship in cost-effective method. The SEEMP provides a monitoring tool which is the Energy Efficiency Operational Index (EEOI) to develop ship and fleet efficiency (IMO, 2014).

The preparation of SEEMP has been made in accordance with some guidelines by developed IMO's Marine Environment Protection Committee (MEPC). The document of MEPC.213 (63) provides guidance for companies in this context. It is not required to be unique

SEEMP because no two shipping company are the same and ships can be operated under a wide range of different conditions. In the light of this guideline, it is required that the framework and structure of the SEEMP should be composed as aspects in the following hierarchical demonstration.

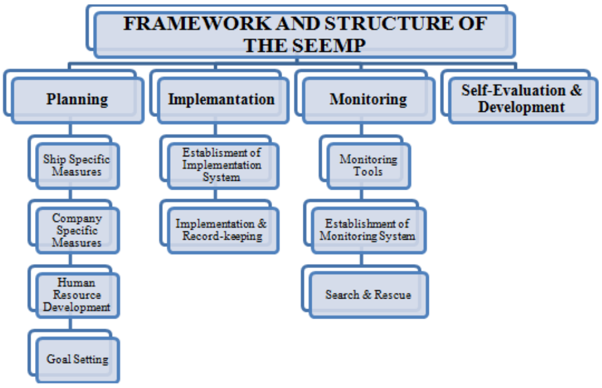

Fig. 1: Frame work and Structure of the SEEMP (MEPC, 2012)

Planning is the most important stage of the SEEMP because correct planning provides to obtain effective results in terms of energy efficiency and it affects all next stages directly. For the SEEMP, it is required that planning should be completed in determined 4 steps in the figure 1. The first step is that ship specific measures and some applicable measures are speed optimization, voyage planning, hull maintenance, engine operations. These examples can always be applied all ship types but some other special measures can be determined by the company for a specific ship operation such as to optimise cargo heating. The second step of the SEEMP planning is company specific measures. Typical examples of these measures are just in time depending on early and good communication among operators, ports, traffic management service and ship to accelerate procedures for optimum port operations and ship fuel management; specifically company can control fuel quality before purchasing and during bunkering operation. Thirdly, human resources development has an important role for planning the SEEMP as well as a critical element of implementation. It provides training and awareness rising for office and ship personnel. Training should be carried on at office as well as on board for ship personnel. The last step of the SEEMP planning is target determining. The goal setting is a voluntary implementation and there is no need to declare the goal and its result but it can be determined to see the result of implementations and to generate an incentive for involved people. MEPC notes that it can take any form such as the annual fuel consumption or a specific Energy Efficiency Operational Index (EEOI) target. The planning stages of the SEEMP can be seen in the MEPC 63/23 guideline in details (MEPC, 2012).

While making investment decision on the potential energy efficiency applications for a specific ship in accordance with the SEEMP, benefit/cost (B/C) matrix can be useful to see financial benefits of the applications.

Table 1: Benefit/Cost Matrix

B/C MATRIX		BENEFIT				
		1	2	3	4	5
COST	5	0.20	0.40	0.60	0.80	1.00
	4	0.25	0.50	0.75	1.00	1.25
	3	0.33	0.67	1.00	1.33	1.67
	2	0.50	1.00	1.50	2.00	2.50
	1	1.00	2.00	3.00	4.00	5.00

The numbers in the figure represent that

- If Benefit/Cost >= 2 Investible
- If 1 =< Benefit/Cost < 2 It should be considered by management
- If Benefit/Cost <1 Non investible

The implementation part covers the establishment of implementation system which is fundamental for improving the energy management procedures by defining roles of qualified personnel for pre-specified tasks. After the establishment, secondly the determined measures in planning stage should be applied for a specific ship in accordance with the predetermined implementation system and the implemented measures and their result should be recorded. It is essential for self-evaluation and required to be incited by IMO guideline (MEPC, 2012). According to IMO, the implementation of the SEEMP was became compulsory for all ships in operation over 400 GT since the 1st of January 2013 (MEPC, 2011).

It is also suggested that the energy efficiency of a ship should be monitored quantitatively and by an established method in compliance with and international standard. In this frame, IMO suggest a monitoring tool which is EEOI and other appropriate quantitative measures can be applied. Robust and reliable energy efficiency management is based on continuous and consistent data collection and MEPC (2009) describes that data collection is the foundation of monitoring whatever measurement tools are used. It is suggested that monitoring should be carried out by utilizing data obtained from ship records by shore staff to avoid overload on ship's staff. The calculation of EEOI is made with the following functions with aid of collected data (MEPC, 2009).

$$EEOI = \frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D} \qquad (1)$$

Where average of the indicator is calculated as below for a period or for a number of voyages is obtained.

$$Average\ EEOI = \frac{\sum_i \sum_j (FC_{ij} \times C_{Fj})}{\sum_i m_{cargo,i} \times Di} \quad (2)$$

Where:

- j is the fuel type;
- i is the voyage number;
- FC_{ij} is the mass of consumed fuel j at voyage i;
- C_{Fj} is the fuel mass to CO_2 mass conversion factor for fuel j;
- $mcargo$ is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships; and
- D is the distance in nautical miles corresponding to the cargo carried or work done.

It is expected that EEOI score should be smaller for more energy efficient ship. According to MEPC (2009), the calculation of EEOI depends on measurement of cargo carried or work done. For a preferable ship operation in terms of energy efficiency, it is required that more amount of cargo for a longer optimum route should be carried with less amount consumption of fuels which contents less carbon. The chemical component of each fuel is different so it cause to have different carbon contents per fuel type and used fuel type is directly affect EEOI value. Also, the fuel mass and CO2 mass has a relationship depending on the chemical composition of the fuel and the fuel mass is converted to CO2 mass by conversion factor which is shown in the following table.

Table 2: The Carbon Content and Conversion Factor per Fuel Type (MEPC, 2009)

Type of Fuel	References	Carbon Contents	C_F (t-CO2/t-fuel)
Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
Liquefied Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
Liquefied Natural Gas (LNG)		0.75	2.750000

The calculation of EEOI is based on operational data from sources such as ship bridge log-book, engine log-book, deck log-book and other official records. It is required by MEPC (2009), data could be collected for a voyage or period in terms of fuel consumption/cargo carried and distance sailed in a continuous sailing pattern as demonstrated in the sample reporting sheet below.

Table 3: CO2 Indicator Reporting Sheet

Name and Type of Ship						
Voyage or Day (i)	Fuel consumption (FC) at sea and in port in tonnes				Voyage or time period data	
	Fuel type ( )	Fuel type ( )	Fuel type ( )		Cargo (m) (tonnes or units)	Distance (D) (NM)
1						
2						
3						

It is noted that it should be recorded to include the fuel used during for voyages in which the amount of carried cargo is zero (mcargo = 0). If it is required, the CO2 indicator may be converted from g/tonne-mile to g/tonne-km by 0.54 multiplication factor (MEPC, 2009).

The last part of the SEEMP is self-evaluation and development. At this stage, it is required that self-evaluation should be applied periodically for the purpose to see effectiveness of the application of the planned measures and to develop more effective energy management system for the next period.

3. EEOI Goal Setting Application for a Chemical Tanker

This study is based on data obtained from ship voyage reports which content berthing and departure times, fuel consumption amounts and types, quantity and carried distance of the cargo for a specific ship and voyage. The data are collected by office staff in order to avoid unnecessary administrative burdens on the ship's staff. The research is carried out for a Chemical/Products Tanker of 6400 DWT which is equipped with a MaK 6M32C Main Engine (ME) of 3000 KW at 600 rpm, three Scania DI 1649M Diesel Generator (DG) Set of 450 KW at 1500 rpm and Gariniaval – Type Auxiliary Boiler (AB) of 1744 KW.

For EEOI calculation, voyage is defined by IMO as "Voyage generally means the period between a departure from a port to departure from the next port" (MEPC, 2009). However, it is noted in related IMO circulars that the alternative definitions of a voyage could be done by shipping companies (MEPC, 2009). According to this suggestion, the voyage and the leg of voyage are defined as the voyage is the period between departure from last discharging port of previous voyage and departure from latest discharging port of present voyage; the leg of voyage is the period between departure from a port and departure from the next port in a voyage. In the light of voyage and leg of voyage definitions, the obtained voyage data which are voyage legs, time of voyage in total and leg-by-leg, fuel type, cargo amount and distance are run by ENCare Software to calculate EEOI scores.

The goal setting is the last part of planning a SEEMP. As it is indicated in the guidelines for the development of SEEMP (MEPC, 2009), the goal setting is a voluntary application and its results may be kept confidential. It is emphasized that the goal setting serves as a signal to rise of consciousness of the involved people to proper implementation of the SEEMP. However, although having a proper SEEMP on board the ship is mandatory since 1 January 2013, there is no a particular method for setting the goal as no method for monitoring EEOI of a specific ship. The absence of a certain method for goal setting has directed ship operators and other stakeholders to seek and adapt appropriate methods for their specific ship or fleet.

In this study, Monte Carlo Simulation method will be used. The reason of the usage of this method is that there are unsatisfactory voyages in numbers in previous years to set 2014 EEOI score goal and the existing voyages' EEOI scores range between wide figures due to different fuel consumptions and voyage details (cargo quantity, distance and fuel type). With the aid of Monte Carlo Simulations, the mean of randomly chosen samples, which are received from voyages in previous year (here 30 voyages in 2013 for 2014 target), is taken by the determined sample size, and as a second step when this process is repeated several times e.g. 1000 times, a stable EEOI score mean is obtained by taking the average of samples' mean. The aim of doing this is to obtain more accurate and reliable EEOI score means by eliminating inconsistency of EEOI scores due to voyage details. This EEOI scores' mean is determined as EEOI goal for next year and it is tried to catch this goal by measures taken. These measures are specified in IMO's SEEMP related guideline (MEPC, 2009) and their contributions to the energy efficiency are also confirmed by the shipping sector.

For the following years, the goal setting is based on the usage of the closest voyages (e.g. last year voyages) in the simulation. Thus more accurate and reliable goal setting is aimed. However, commercial priorities and applied strategies (fast sailing because of demurrage, ballast voyages, preference on high carbon factor fuel usage etc.) can affect seizing the goal in a negative way. Thus, operated voyages EEOI scores may show a change regarding to commercial and different strategic applications of the ship owners. Hereby the applied measures could be introduced as optimal tools to catch the set goals. For example the 2015 target is determined by EEOI scores which were obtained in 2014 voyages, but 2015 target could be high or low depending on EEOI scores in 2014.

The aim of using Monte Carlo Simulation is to set more realistic and seizable goals by using ship-specific and company-specific measures regardless of the negative effect of some company commercial policies and strategies. In this method, randomly and repeated several times observations are key to eliminate statistically irrelevant EEOI scores' effects. Dice example and mathematical explanation of the method is given as follow.

According to the law of large numbers, when the number of observation is raised, the average of the observations will converge to the long term average of the variable which is μ. The mathematical statement of the law is given as follow.

$$\lim_{n\to\infty} \bar{X} = \mu \tag{3}$$

The equation 3 presents that the obtained average of variable ($\bar{X}$) from trials will converge to the long term average μ. The following graphic clearly shows that the average dice value will correspond to 3.5 when the trials are increased.

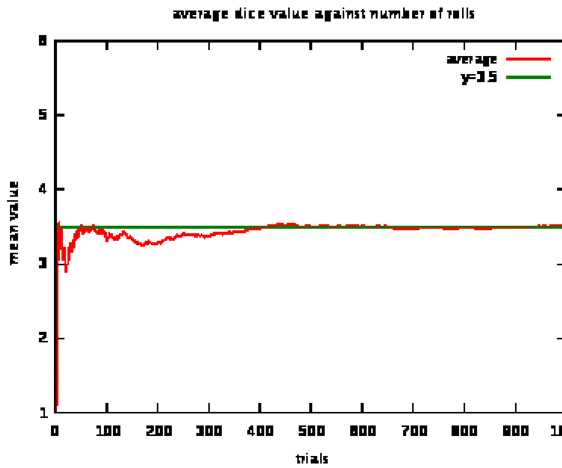

Fig. 2: The average dice value against number of rolls

If the sufficient amount EEOI scores are obtained, the long term EEOI average could be estimated. Nevertheless, if there is no sufficient voyage to estimate effectively what the accurate EEOI score average is, at this point, the usage of the convenient simulation methods are required.

The central limit theorem gives that the average of a factor (here EEOI score), which shows same distribution and finite variance, will distribute normally if there are sufficient observation values at any distribution. The mathematical statement of the central limit theorem is given as follow.

$$\lim_{n\to\infty} \bar{X} \sim N(\bar{\bar{X}}, \sigma_{\bar{X}}^2) \tag{4}$$

The above equation states that the observation average of a factor ($\bar{X}$) will distribute normally with the average ($\bar{\bar{X}}$) and variance ($\sigma_{\bar{X}}^2$). From the point of EEOI, the equation presents that the long term average of EEOI scores will distribute normally with the average($\overline{EEOI}$) and the variance ($\sigma_{\overline{EEOI}}^2$).

In the frame of these theorems, the key point is that the no of observations to analysis EEOI values correctly and to obtain close EEOI value mean from observations to actual EEOI mean. For a realistic simulation, EEOI values are simulated by Monte Carlo method.

The steps of the Monte Carlo approach;

- The all EEOI scores of the past voyages are calculated to determine the long-term EEOI targets.

- The new voyages are simulated by using a certain sample group from the obtained scores and for these voyages, EEOI mean ($\overline{\text{EEOI}}$) is calculated. The number of voyages will be simulated should be big enough. Thus, according to the law of large numbers, the mean of the obtained EEOI score will converge to the actual long-term mean of the EEOI score.
- The mean of the all EEOI scores' means which are obtained from simulation is calculated. It will distribute normally according to the central limit theorem.
- The confidence interval is formed at α = 0.01 (99% certainty) the significance level. The formulation demonstration of the confidence interval is as follow.

$$\overline{EEOI_i} = \frac{\sum_{i=1}^{n} EEOI_i}{n} \quad (5)$$

Where,

- $\overline{\text{EEOI}_i}$ = The mean of EEOI score,
- n = The number of observation,

$$\overline{\overline{EEOI}} = \frac{\sum_{i=1}^{n} \overline{EEOI_i}}{n} \quad (6)$$

Where,

- $\overline{\overline{\text{EEOI}}}$ = The mean of the mean of EEOI score,
- n = The number of $\overline{\text{EEOI}}$,

$$\sigma_{\overline{EEOI}} = \sqrt{\frac{\sum_{i=1}^{n}(\overline{EEOI_i} - \overline{\overline{EEOI}})^2}{n-1}} \quad (7)$$

Where,

- $\sigma_{\overline{\text{EEOI}}}$ = The standart deviation of the $\overline{\text{EEOI}}$ values,
- n = The number of $\overline{\text{EEOI}}$,

$$\sigma_{\overline{\overline{EEOI}}} = \frac{\sigma_{\overline{EEOI}}}{\sqrt{n}} \quad (8)$$

Where,

- $\sigma_{\overline{\overline{\text{EEOI}}}}$ = The standart error of $\overline{\overline{\text{EEOI}}}$,
- n = The number of $\overline{\text{EEOI}}$

The confidence interval;

$$\overline{\overline{EEOI}} - z_{a/2} * \sigma_{\overline{\overline{EEOI}}} < \mu_{EEOI} < \overline{\overline{EEOI}} + z_{a/2} * \sigma_{\overline{\overline{EEOI}}} \quad (9)$$

Where,

- $z_{a/2}$= The table critical value of the normal distribution

In this circumstances,

$$P\left(\overline{\overline{EEOI}} - z_{a/2} * \sigma_{\overline{\overline{EEOI}}} < \mu_{EEOI} < \overline{\overline{EEOI}} + z_{a/2} * \sigma_{\overline{\overline{EEOI}}}\right) = 0.99 \quad (10)$$

Where,

- $P = Probability\ Value$

The last equation represents that the long-term actual value of EEOI mean will probably be between lower and upper limits of the confidence interval with 99%. The application of the Monte Carlo is simply illuminated for EEOI target determination as follow.

- The calculation of past EEOI scores,
- The determination of the size of sample group for the simulation; this sample group is choose from inside past EEOI scores randomly at certain size. There is no exact rule in order to determine the size of the sample group but a percental rate of the mass is used such as 10%, 15% or 20% etc.
- The determination how many times the simulation will be run; the number of the simulation is determined according to the law of large numbers and so this value will be between 100 and 1000.
- The calculation of the EEOI score mean for the selected sample group; the calculation is made by the following formula,

$$\overline{EEOI_i} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k}(F_j \times CF_j)}{\sum_{j=1}^{k \times n} M_j \times D_j} \quad (11)$$

Where,

$\overline{EEOI_i}$; The EEOI score mean for term *i* (CO_2/mt x nm)

F_j; The used fuel type at leg *j* (mt)

CF_j; The carbon conversion factor for used fuel type at leg *j*

M_j; The carried cargo amount at leg *j* (mt)

D_j; The distance at leg *j* (nm)

The obtained EEOI value is recorded as $\overline{EEOI_i}$. It is accepted as an estimator for the next voyage term.

- The formation of the virtual voyages; at this stage, the sample group is selected as much as the determined simulation amount and $\overline{\text{EEOI}}$ values are calculated with the aid of the equation 11. For example;$\overline{\text{EEOI}}_1$,$\overline{\text{EEOI}}_2$,$\overline{\text{EEOI}}_3$,....., $\overline{\text{EEOI}}_i$

- The calculation of the mean of the EEOI scores' mean; it is calculated with the following equation.

$$\overline{\overline{EEOI}} = \frac{\sum_{i=1}^{n} \overline{EEOI_i}}{n} \qquad (12)$$

Where,

n; the number of the virtual voyages

- The determination of the long-term EEOI target; for the target EEOI score, the confidence interval lower limit is formed with equations x to y. This lower limit is determined as the next term EEOI target.

4. Results

As it is explained in the previous stage, the Monte Carlo Simulation method was used to determine the EEOI for the year 2014 with aid of the previous year EEOI scores. Figure 3 shows the screen shot of the ENCare program which calculates EEOI target by using the Monte Carlo Simulation. The program gives chance to define parameters such as observation, sample ratio, probability and past year scores.

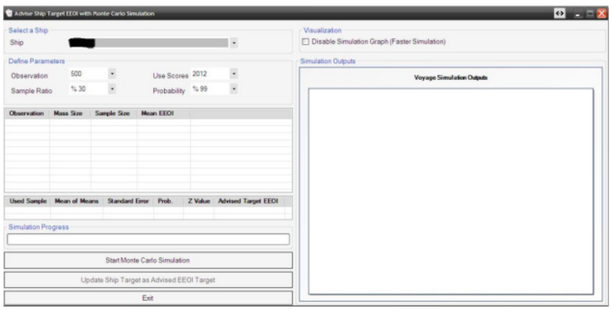

Fig. 3: Screen Shot of the ENCare Program

The results, namely yearly target, obtained from the run simulation on the ENCare program are presented in Figure 4. The figure also provides 30 voyages in the horizontal axis which are operated during 9 months in 2014, and the EEOI mean of these voyages. It is apparent from this figure that the target is achieved for the year 2014, despite the EEOI scores of the early voyages look very high to seize determined target. While the target score for EEOI was 26.63 E-06 CO_2/ton*nm, the obtained mean score is 15.97 E-06 CO_2/ton*nm. Interestingly, this graphic show similarity dice example in figure 2 and it can be said that the applied method to determine EEOI target is correct to achieve the required results.

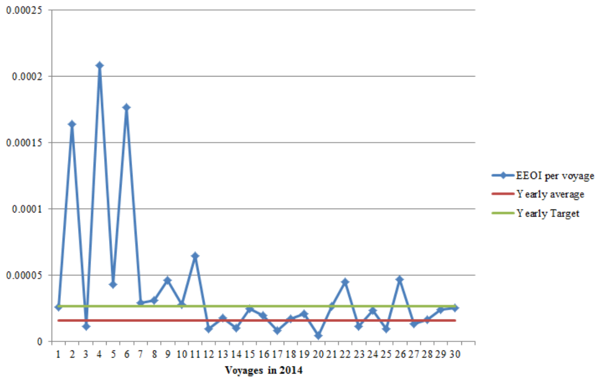

Fig. 4: The illustration of EEOI scores of voyages, their mean and EEOI target in 2014

The details of the voyages, which are consumed fuels, carried cargo quantity and sailed distance during the voyages, can be seen in the below two graphics. For the lower EEOI score, it is required that the fuel consumption should be kept at minimum level during the voyage and the usage of fuels with the lower carbon conversion factor. According to data from the ship, 3 types of fuels were consumed during this term. The most consumed fuel type is LSFO and it is followed by MGO and HSFO respectively. When CO_2 conversion factor of fuels is considered, it can be said that LSFO and HSFO consumptions can impact EEOI scores positively more than MGO. In other words, it is required that the ship should sail as much as possible because LSFO and HSFO are mostly preferred to use at main engine during sailing and their carbon conversion factors are less than MGO.

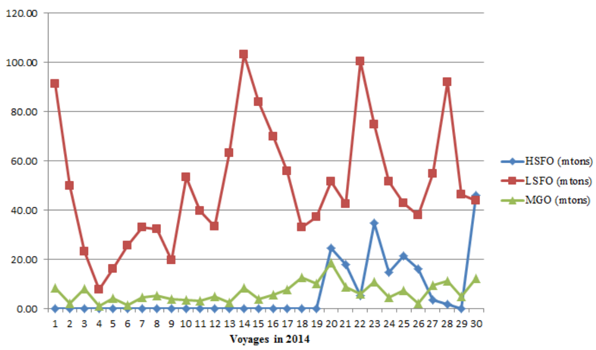

Fig. 5: Fuel consumptions of voyages in 2014

Another graphic shows the carried quantity and the sailed distance of voyages in 2014. In contrary to fuel consumption, it is required that high quantity cargoes should be carried on long voyages for lower EEOI score. The most suitable example is the voyage 20 for this situation; in that, the carried cargo amount is reasonable and it was carried on the longest route among other voyages. This voyage has the lowest EEOI score. The sustainability of the lowest EEOI scores is possible with the application the most suitable ship-specific SEEMPs.

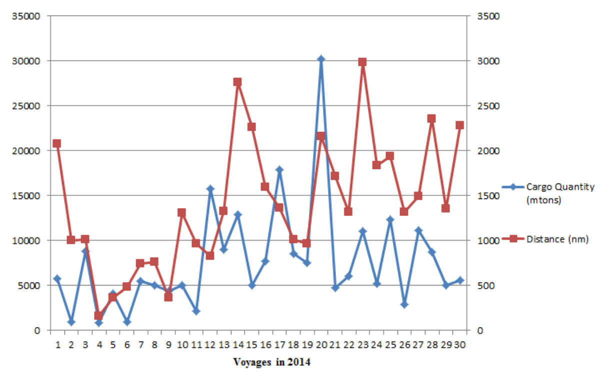

Fig. 6: Carried cargo quantity and sailed distance of voyages in 2014

A strong relationship between the EEOI score and the mentioned details of voyages has been reported in this part. The reasonable EEOI target setting principles depend the minimum fuel consumption for carriage of unit cargo per kilometer or mile. As aforementioned, it is provided by the ship-specific SEEMP.

5. Conclusions

The present study was designed to determine the EEOI target for next year/s by using past years EEOI scores. The results have been obtained with aid of the Monte Carlo Simulation approach. The relevance of the law of the large number and the central limit theorem is clearly supported by the current findings. The most obvious finding to emerge from this study is that the determined 2014 EEOI goal has been seized according to EEOI score outputs of the voyages in 2014. The methods used for this EEOI targeting may be applied to other EEOI targeting studies else ships in the world. As a conclusion, the suitable application of the ship-based specific SEEMP with its all steps, which are planning, implementation, monitoring and self-evaluation & development, is key factor to obtained reasonable EEOI scores. The self-evaluation & development stage is important to improve the determined measures to reduce EEOI scores of future voyages.

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