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IMPLEMENTATION OF ENERGY EFFICIENCY MANAGEMENT IN SHIPPING COMPANIES AND SHIPS IN OPERATION

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Purpose: reasons for writing the paper is to present and explained implemented on board seaging vessels energy efficiency management and give an answer to question how SEEMPs are implemented and applied in day to day operation.
Design/methodology/approach: an analysis of various shipping companies and ships Ship Energy Efficiency Management Plans.
Findings: found that application of SEEMP are varied between shipping companies and is not very well known on board vessels.
Research limitations/implications: SEEMP to be clearly explained to ships crew for better understanding and application in day to day operation.
Practical implications: suggestion to Shipping Management Companies to simplify SEEMPs.
Social implications: reduction of GHG emission.
Originality/value: implementation of best practices to improve EEOI.

Keywords: Ship Energy Efficiency Management Plan, EEOI, Best Practices

Category of the paper: research and viewpoint paper.

1. Introduction

Ship Energy Efficiency Management Plan (SEEMP) was made mandatory for all ships at IMO – **M**arine Environmental **P**rotection **C**ommittee –MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (resolution MEPC.203(62)), by Parties to MARPOL Annex VI. This was the first legally binding climate change treaty to be adopted since the Kyoto Protocol. In this paper authors intended to present and explained implemented on board seaging vessels energy efficiency management and give an answer to question how SEEMPs are implemented and applied in day to day operation.

The **S**hip **E**nergy **E**fficiency **M**anagement **P**lan (SEEMP) is an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner. The SEEMP also provides an approach for shipping companies to manage ship and fleet

efficiency performance over time using, for example, the **E**nergy **E**fficiency **O**perational **I**ndicator (EEOI) as a monitoring tool. The guidance on the development of the SEEMP for new and existing ships incorporates best practices for fuel efficient ship operation, as well as guidelines for voluntary use of the EEOI for new and existing ships (MEPC.1/Circ.684). The EEOI enables operators to measure the fuel efficiency of a ship in operation and to gauge the effect of any changes in operation, e.g. improved voyage planning or more frequent propeller cleaning, or introduction of technical measures such as waste heat recovery systems or a new propeller. The SEEMP urges the ship owner and operator at each stage of the plan to consider new technologies and practices when seeking to optimise the performance of a ship.

Implemented **E**nergy **E**fficiency **D**esign **I**ndex is the most important technical measure and aims at promoting the use of more energy efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments. Since 1 January 2013, following an initial two year phase zero, new ship design needs to meet the reference level for their ship type. The level is to be tightened incrementally every five years, and so the EEDI is expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase. The EEDI is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions for the ship to comply with the regulations. The EEDI provides a specific figure for an individual ship design, expressed in grams of carbon dioxide (CO_2) per ship's capacity-mile (the smaller the EEDI the more energy efficient ship design) and is calculated by a formula based on the technical design parameters for a given ship. The CO_2 reduction level (grams of CO_2 per tonne mile) for the first phase is set to 10% and will be tightened every five years to keep pace with technological developments of new efficiency and reduction measures. Reduction rates have been established until the period 2025 and onwards when a 30% reduction is mandated for applicable ship types calculated from a reference line representing the average efficiency for ships built between 2000 and 2010. The EEDI is developed for the largest and most energy intensive segments of the world merchant fleet and embraces emissions from new ships covering the following ship types: tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers and combination carriers. In 2014, MEPC adopted amendments to the EEDI regulations to extend the scope of EEDI to: LNG carriers, ro-ro cargo ships (vehicle carriers), ro-ro cargo ships; ro-ro passenger ships and cruise passenger ships having non-conventional propulsion. These amendments mean that ship types responsible for approximately 85% of the CO_2 emissions from international shipping are incorporated under the international regulatory regime.

MEPC 70 (October 2016) adopted mandatory MARPOL Annex VI requirements for ships to record and report their fuel oil consumption, by resolution MEPC.278(70). In relation to the amendments to MARPOL Annex VI on the mandatory data collection systems for fuel oil consumption of ships, MEPC 70 also adopted the 2016 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP), by resolution MEPC.282(70). Under the amendments to MARPOL Annex VI, on or before 31 December 2018, in the case of a ship of 5,000 gross tonnage and above, the SEEMP shall include a description of the methodology that will be used to collect the data and the processes that will be used to report the data to the ship's flag State (MARPOL Consolidated..., 2017; MARPOL Annex…, 2017; Ship…, 2008; Ship…, 2009).

2. Guidelines for Ship Energy Efficiency Management Plan (SEEMP) and Energy Efficiency Operational Indicator (EEOI)

In order to robust environmental protection in a practice, shipping company should establish Energy Management Policy as follows (tankership company as example) (Finnley, 2018; Josi, 2021; Smith, 2020):

1. The Company shall establish Ship Efficient Energy Management Plan (SEEMP) for both the Onshore and Onboard, which refers IMO MEPC.1/Circ.683 (SEEMP), OCIMF Energy Efficiency and Fuel Management (EEFM) and Intertanko Guide for a Tanker Energy Efficiency Management Plan (TEEMP).
2. The Plan shall be specific for individual vessels and reviewed regularly by both the vessel and the Company senior managements.
3. The Company shall set goals for energy management that shall be quantified Energy Efficiency Operational Index (EEOI) in accordance with IMO MEPC.1/Circ.684 (Ship…, 2009).
4. The continuous improvement process for efficiency energy management shall be based on the Company HSEQ system (IMS) that complies latest ISO 14001.

2.1. Ship Energy Efficiency Management Plan

A Ship Energy Efficiency Management Plan (SEEMP), is ship-specific document containing energy efficiency improvement measures identified by the Ship Owner, to be kept onboard each ship. A Ship Energy Efficiency Management Plan (SEEMP), being introduced as an operational measure, is a tool for monitoring ship and fleet energy efficiency performance over time and improving it with a PDCA (Plan-Do-Check-Act) cycle.

It encourages the ship-owner, to incorporate new technologies and adopt best management practices to ensure an energy efficient ship operation. It has been widely recognized that if efficiency of ship operations were improved, then carbon emissions could be reduced significantly. The purpose of introducing SEEMP is to assist Ship Owners to use it as an energy management tool in managing energy efficiency of their ships. The SEEMP approach seeks to improve a ship's energy efficiency through four steps:

- Planning.
- Implementation.
- Monitoring.
- Self-evaluation and Improvement.

SEEMP is to be available onboard during the first renewal or intermediate survey on or after 1st January 2013 and is mandatory for all ships of 400 GT and above (MARPOL Consolidated…, 2017; MARPOL Annex…, 2017).

Unfortunately, research done on board many sea-going vessel on SEEMPs gives an answer that ships crew is not well acquainted with that subject and there is still room for improvement.

2.2. Energy Efficiency Operational Indicator (EEOI)

Indicator = MCO_2 / (transport work)

In general, cargo mass carried or work done is expressed as follows:

- for dry cargo carriers, liquid tankers, gas tankers, ro-ro cargo ships and general cargo ships, metric tonnes (t) of the cargo carried should be used.
- for containerships carrying solely containers, number of containers (TEU) or metric tons (t) of the total mass of cargo and containers should be used.
- for ships carrying a combination of containers and other cargoes, a TEU mass of 10 tonnes could be applied for loaded TEUs and 2 tonnes for empty TEUs,
- for passenger ships, including ro-ro passenger ships, number of passengers or gross tonnes of the ship should be used,
- for car ferries and car carriers, number of car units or occupied lane meters,
- for containerships, number of TEUs (empty or full); for railway and ro-ro vessels, number of railway cars and freight vehicles, or occupied lane meters.

Fuel mass to CO_2 mass conversion factors (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:

Table 1.
Values of Conversion factors C_F depend of brand of fuel

Type of fuel	Reference	Carbon content	CF (t-CO2/t-Fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

Fuel consumption, FC, is defined as all fuel consumed at sea and in port or for a voyage or period in question, e.g. a day, by main and auxiliary engines including boilers and incinerators.

Distance sailed means the actual distance sailed in nautical miles (deck log-book data) for the voyage or period in question.

Voyage generally means the period between a departure from a port to the departure from the next port. Alternative definitions of a voyage could also be acceptable.

The basic expression for EEOI for a voyage is defined as:

$$\text{EEOI} = \frac{\sum_j FC_j \, xC_{Fj}}{m_{cargo} \, x \, D} \tag{1}$$

Where average of the indicator for a period or for a number of voyages is obtained, the Indicatoris calculated as:

$$\text{Avarage EEOI} = \frac{\sum_i \sum_j (FC_{ij} \, xC_{Fj})}{\sum_i (m_{cargo,i} \, x \, D_i)} \tag{2}$$

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,*

m_{Cargo} is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships,

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

The unit of EEOI depends on the measurement of cargo carried or work done, e.g., tonnes CO_2 / (tonnes • nautical miles), tonnes CO_2 / (TEU nautical miles), tonnes CO_2 / (person • nautical miles), etc. It should be noted that Equation 2 does not give a simple average of EEOI among number of voyage *i*. Rolling average, when used, can be calculated in a suitable time period, for example one year closest to the end of a voyage for that period, or number of voyages, for example six or ten voyages, which are agreed as statistically relevant to the initial averaging period. The Rolling Average EEOI is then calculated for this period or number of voyages by Equation 2 above (Seah, 2009; Cooper, Gustafsson, 2017).

2.3. Monitoring System

The monitoring system, including the procedures for collecting data and the assignment of responsible personnel are described below:

1. Data collecting procedure: Calculation of fuel consumption shall be on a daily basis and entered into the Engine Room Log Book. Data collection (vessel speed, position, weather condition shall be on a daily basis by entering data into voyage log.
2. Reporting procedure: Voyage data collected by the above process shall be submitted to the Company after completion of every voyage. From the calendar year 2019, each ship of 5,000 gross tonnage and above shall collect the data specified in appendix IX to the Annex VI of MARPOL, for that and each subsequent calendar year or portion thereof, as appropriate, according to the methodology included in the SEEMP.
3. Setting Targets: The purpose of setting targets is to serve as a signal which involved people should be conscious of, to create a good incentive for proper implementation, and then to increase commitment to the improvement of energy efficiency. It shall be a specific target of Energy Efficiency Operational Indicator (EEOI). Comparison of obtained EEOI with determined the Target EEOI giving answer how effective is SEEMP implemented on particular vessel. Responsible person to determine Target EEOI is Company Management Representative

2.4. Self-Evaluation and Improvement

Self-evaluation and improvement is the final phase of the management cycle. This phase should produce meaningful feedback for the coming first stage, i.e. planning stage of the next improvement cycle. The purpose of self-evaluation is to evaluate the effectiveness of the planned measures and of their implementation, to deepen the understanding on the overall characteristics of the ship's operation such as what types of measures can/cannot function effectively, and how and/or why, to comprehend the trend of the efficiency improvement of that ship and to develop the improved SEEMP for the next cycle (Ship…, 2008; Ship…, 2009).

Self-evaluation on board for Energy Efficiency shall be done during Committee Meeting as described below:

Time of Evaluation: January, April, July and October (Every Quarter).
Opportunity: Shipboard Management Committee Meeting.
Chairman: Master.
Participants: Deck and Engine Officers, as minimum.
Agendas:

- Evaluation of achieved EEOI against the Target.
- Trends of achieved EEOI in passed year and the evaluated period.
- Comparison with the Best Practices that will be provided by the Company.
- Evaluations of the achievements on the vessel plan (Measures).

- Evaluation what types of measures can/cannot function effectively, and and/or why.
- Develop the improved SEEMP for the next cycle

Recording: Record of the Self-Evaluation shall be recorded.

3. Planning for measures to improve EEOI

Planning is the most crucial stage of the SEEMP, in that it primarily determines both the current status of ship energy usage and the expected improvement of ship energy efficiency. It is important to establish ship specific measures. Below mentioned subjects to be taken into consideration.

1. Recognizing that there are a variety of options to improve efficiency – speed optimization, weather routing and hull maintenance, for example – and that the best package of measures for a ship to improve efficiency differs to a great extent depending upon ship type, cargoes, routes and other factors, the specific measures for the ship to improve energy efficiency should be identified in the first place. These measures should be listed as a package of measures to be implemented. The overview of the recommended actions is listed in after-mentioned matrix as "Best Practices".
2. During this process, therefore, it is important to determine and understand the ship's current status of energy usage. The SEEMP then identifies energy-saving measures that have been undertaken, and determines how effective these measures are in terms of improving energy efficiency. The SEEMP also identifies what measures can be adopted to further improve the energy efficiency of the ship.
3. Guidance on Best Practices for Fuel-Efficient Operation of Ships set out in the matrix below can be used to facilitate this part of the planning phase (Ship…, 2009; Josi, 2021).

The improvement of energy efficiency of ship operation does not necessarily depend on single ship management only. Rather, it may depend on many stakeholders including ship repair yards, shipowners, operators, charterers, cargo owners, ports and traffic management services. The better coordination among such stakeholders is, the more improvement can be expected. In most cases, such coordination or total management is better made by the Company rather than by a vessel. The SEEMP (On Shore) is established to manage the fleets and make necessary coordination among stakeholders, etc. (Finnley, 2018; Smith, 2020; Josi, 2021).

For effective and steady implementation of the adopted measures, raising awareness of and providing necessary training for personnel both on shore and on board are an important element. Such human resource development is encouraged and should be considered as an important component of planning as well as a critical element of implementation.

3.1. Measures –Best practice guideline

Effective measures to be implemented in the various area of ship operation. In this chapter example of the measures is presented. Specific measures applied on board the vessel can be different and are not limited to measures given in the presented example (Mikulski, 2015; Danney, 2017; Finnley, 2018; Smith, 2020; Josi, 2021).

1. **Voyage Planning**

Vessel to optimise route plan by "avoid bad weather" or "strong adverse currents" while also maximising the use of "tidal streams" and "ocean currents".

The above aspects shall be determined within the limitations of traffic separation scheme and safe navigation in line with the guidelines described in the publication of "Bridge Team Management (basis IMO Guideline for Voyage Planning (Ship…, 2008). Second Officer is responsible for Voyage Planning under supervision of the Master.

2. **Weather Routeing**

Utilizing and, to monitor the weather and Hydrographic forecast and incorporate this data into the voyage plan. The Master is responsible for utilizing the weather routing.

3. **Just in Time (Ship-Shore liaison)**

Vessel should actively liaise with the operator/charterer/local agents/port authority to confirm required voyage schedule and set optimum speed under approval of the operator taking an appropriate safe margin into account. The Master is responsible to actively liaise with the operator/charterer for voyage schedule.

4. **Speed Optimisation**

The Master is responsible to optimise vessel speed Vessel to optimise the speed, where practical, maintaining the most fuel efficient speed to minimise total fuel consumed throughout the entire voyage. Optimum speed means the speed at which the fuel used per tonne mile is at a minimum level for that voyage. It does not mean minimum speed (Ship…, 2008). The Master is responsible to optimise vessel speed.

5. **Optimised Shaft Power**

Main engine power to be limited to 85% of the Maximum Continuous Rating (MCR) and to 90% thermal load. Vessel to reduce any Unnecessary load whenever possible. Chief Engineer is responsible for not to exceed 85% MCR and to 90% thermal load. Vessel to operation at constant shaft RPM which can be more efficient than continuously adjusting speed through engine power. The Master and Chief Engineer is responsible to set appropriate RPM taking fuel efficiency into account.

6. **Optimum Trim**

Vessel to ensure the appropriate optimum trim. The optimum trim for the ballast passage should be tested and compared with other ballast conditions as per the procedure required by the Company. The Master and Chief Engineer is responsible to set appropriate RPM taking fuel efficiency into account.

7. **Optimum Ballast**
   - Vessel to ensure adjusting Ballast taking into consideration on optimum trim and steering conditions and optimum ballast conditions achieved through good cargo planning. The Plan shall meet requirements of Ballast Water Management Plan. Chief Officer is responsible for cargo planning taking optimum ballast into account.
   - Vessel to ensure that present ballast conditions does not have a negative impact on steering conditions and Auto-Pilot settings. Such condition may effect deterioration of fuel efficiency, as well as the safe navigation. The OOW (officer on watch) is responsible to constant monitoring on steering and Auto-Pilot conditions and report to the Master of any negative influence. The Master is responsible to verify steering and Auto-Pilot condition and does necessary adjustment on ballast or setting Auto-Pilot.
8. **Optimum use of Rudder and Heading control systems (Autopilots)**

Master and Officer on watch are responsible for this measures:

- Vessel to ensure, when navigating open sea without obstruction for safe navigation, maintaining position on the course line through a close position check on "ECDIS" and the other available means.
- Vessel to ensure that the setting of Auto-Pilot is optimised considering the situation around. Especially, when the vessel is navigating open sea without obstruction for safe navigation, set in "Economical mode" as far as practicable.
- Vessel to ensure that the action to avoid a vessel is to be in ample time to avoid close-quarter situation. It is not only for the safety but also fuel efficiency, avoiding a quick load & changing engine revolution.
- Vessel to ensure changing over from Auto-Pilot to Hand-Steering in ample time when approaching to ports and confined waters. It is not only for the safety but also fuel efficiency, since the Auto-Pilot cannot always be used efficiently as the rudder has to respond quickly to given commands.
- Vessel to ensure changing over from Auto-Pilot to Hand-Steering at certain stage of heavy weather. This is not only the safety but also the fuel efficiency.

9. **Maintenance General**

Vessels to ensure number of outstanding tasks in Planned Maintenance System (PMS) are less then **1%** (Year to date). The Chief Engineer is responsible for PMS system with cooperation of Master.

10. Propulsion System Maintenance (Ship…, 2009)

Chief Engineer is responsible to consider additional measures to improve engine efficiency:

- Vessel to ensure Performance check of Maine Engine to make sure a balanced output from all cylinders. The check shall take place which interval should not be less than 10 propelling days (or once per each Ballast and Laden voyages).
- Vessel to ensure optimizing Alpha Lubrication system by adjusting the feed rate according to the fuel quality.
- Vessel to ensure optimisation of Propulsion system using additional means to improve engine efficiency, which may include: use of fuel additives, adjustment of cylinder lubrication oil consumption, torque analysis, automated engine monitoring systems.

11. Waste Heat Recovery

Chief Engineer is responsible for this measures:

- Vessel to maintain the exhaust valves and associated piping system, etc. ensuring that the maximum amount of heat is recovered for steam and power generation.
- Vessel to ensure efficient operation of the main engine cooling water by the continued effective treatment of the cooling water to reduce scale, corrosion etc.
- Vessel to ensure efficient operation EGE by soot blowing, which minimum twice a day while at sea in the circumstance is permit.
- Soot blowing shall also be conducted, before entering and after sailing ports at an area where environmentally safe and ensure that the hot Water system is operated within the parameters required as per the SMS.

12. Energy Management

Chief Engineer is responsible for this measures:

- Vessel to inspect the insulation of the exhaust gas trunk and maintain it in good condition.
- Steam Systems (Saturated and Super-heated) Vessel to ensure that all piping continues to be maintained no leaking and insulated to retain temperature efficiency.
- Vessel to ensure the continued maintenance of the settling and service tanks etc. with particular regard to insulation, vent heads etc.
- Vessel to ensure that all piping with the insulation continues to be maintained in a satisfactory condition, able to maintain the set pressures.
- Vessel to record daily consumption, speed, vessel condition (laden or ballast), weather, sea state and wind direction into voyage record.
- Vessel to calculate on a daily basis the % power and thermal load compared to that at the MCR.

13. Improved Fleet Management

Vessel should hold Energy Efficient review committee at quarterly basis (Jan., Apr., Jul., and Oct.) for the following items. The Master is responsible to chair the committee and final evaluation.

14. Fuel Management

Vessel to ensure management of fuel on board in optimum operational condition in accordance with the Company "Fuel Management Procedure" to minimise sludge production" and "keep the plant in optimum operational condition". Vessel to accurately measure Fuel consumption of Main Engines, Boilers and Auxiliaries and record. Chief Engineer is responsible to maintain fuel on board in optimum condition.

15. Power Generator Optimisation

Chief Engineer is responsible for this measures.

- Vessel to utilize the diesel generator(s) at their optimum load, minimizing low load operation as much as possible.
- Vessel to ensure Performance check of diesel generator engine to make sure a balanced output from all cylinders.
- Vessel to utilize the turbo generator as frequently as possible.

16. Training

Vessel to ensure awareness of crewmembers for efficient energy management using the SEEMP and the training materials. Awareness training shall take place before or after On board Management Committee Meeting. The Master id responsible for the awareness training.

4. Role of Seafarers in SEEMP

Seafarers play a crucial role in implementing the SEEMPs onboard ships and also in providing the feedback, reports, performance etc. to the shore office which is further used to enhance the plan (Finnley, 2018; Smith, 2020). Following are some of the essential roles which a seafarer plays in SEEMP:

- Implementing the procedure as laid down in the SEEMP.
- Monitoring the performance of the SEEMP procedures and how it is affecting the ship operation.
- Collecting reports, and sending the logs, performance etc. to the company for evaluation.
- Establishing a safety and sustainability culture onboard ship to add to the energy efficiency of the ship.

- Efficiently managing the cargo operation when in port and maintaining the ship's machinery to avoid breakdown and delays to the shipping schedule.
- Implementing correct and modern navigation technique for the optimized voyage planning.

SEEMP is not a set rule of operations and it has to evolve in terms of providing better energy saving solutions than the previous ones. The improvisation of SEEMP highly depends on the different parties involved in the shipping operation such as Port operator, Ship owners, shipyard, ship managers, seafarers etc.

Authors of this paper are giving strong suggestion to Shipping Management Companies to simplify SEEMPs for better understanding the goals and possible results of it application on board the managed ships. Intensive training on the subject discussed for ships crew would be recommended. Trough implementation of best practices to improve EEOI reduction of GHG emission form ships will take place.

5. Conclusion

1. Ship energy efficiency management plan (SEEMP) is a ship specific plan that provides a mechanism to improve the energy efficiency of a ship in a cost-effective manner.
2. If the ship uses some innovative technology that reduces the wastage of the mechanical energy produced or that increases the efficiency of the engines, the ship would be more energy efficient and hence will contribute towards lesser attained EEDI value.
3. When a vessel complies with requirements stated in MARPOL –Annex IV and resolutions MEPC, the ship obtains a certificate named "International energy efficiency certificate".
4. The difference between these two terms EEDI and EEOI is that EEDI is the measure of energy efficiency of the ship by design and EEOI is the measure of how efficiently the ships are operated.
5. The concept of ship energy efficiency is related to the emission of CO_2 and reduction of GHG (green house gases)
6. Research done on board many sea-going vessel on SEEMPs gives an answer that ships crew is not well acquainted with that subject and there is still room for improvement.

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