# TECHNICAL AND ECONOMIC EVALUATION OF IMPLEMENTING SHIP ENERGY EFFICIENCY MANAGEMENT PLAN (SEEMP) ON STEAM PROPULSION LNG CARRIER

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M. N. A. Rosmani,[a] N. Ismail,[a,*]

[a] Faculty of Mechanical Engineering (FKM)
Univerisiti Teknologi Malaysia
81310 UTM SKudai, Johor, Malaysia.

*Corresponding author
nasrudin@mail.fkm.utm.my

## ABSTRACT

Ship Energy Efficiency Management Plan (SEEMP) is a simple approach for monitoring ship and fleet efficiency performances from time to time as well as for emission monitoring and reduction as mentioned as in the rule and regulation. SEEMP also provides some options to be considered to optimize ships efficiency to reduce emission. SEEMP consists of four stages. The first stage is the planning stage, followed by implementation, monitoring and self-evaluation, and finally improvement stage. In the planning stage, any ship-specific measures that can be implemented on board the ship to improve the ship efficiency as well as to reduce emission are determined. After the ship-specific measures are implemented, they will be monitored in the third stage by using Energy Efficiency Operational Indicator (EEOI). In the final stage, an overall analysis from the data collected in the monitoring stage are analyzed in order to deepen the understanding on the overall characteristics of the ship's operation, such as which type of measures that can or cannot function effectively and lastly to improve the SEEMP for the next cycle. This project focuses on how to implement the SEEMP on a steam propulsion LNG carrier. Technical and economic evaluations of SEEMP implementation on steam propulsion LNG carrier have been carried out for weather routing optimization and asymmetry pre-swirl stator.

## KEYWORDS

Energy Efficiency Operational Indicator (EEOI); Ship Energy Efficiency Management Plan (SEEMP); Liquefied Natural Gas (LNG);

## INTRODUCTION

International Maritime Organization (IMO) is a specialized agency of the United Nation responsible for monitoring to improve the safety and security of international shipping and to prevent marine pollution caused by ship emissions. IMO has developed a number of technical and operational measures such as SEEMP [1] and EEOI [2] in order to regulate shipping energy efficiency and indirectly control the marine Green House Gas (GHG) emissions. This greenhouse effect causes destruction to the earth atmosphere, such as rise in the global temperature and sea water level which can harm living things. This project focuses on identifying the parameters for evaluation, as well as to establish the procedure for implementation of SEEMP on steam propulsion LNG carrier to increase ship efficiency and reduce emission by ships.

## TECHNICAL EVALUATION OF SEEMP IMPLEMENTATION

### Weather Routing Optimization

The steps to implement weather routing optimisation on steam propulsion LNG carrier are described in the next subsection.

#### Planning

The parameters for evaluation SEEMP on steam propulsion LNG carrier for weather routing optimization are shown in Table 1.

Table 1: Weather Routing Optimization Parameters

| Method of energy efficiency improvement | Primary Parameters | Secondary parameters |
|---|---|---|
| Weather Routing Optimization | -Different sea condition.<br><br>-Different route. | -Different Speed.<br>-Distance sail<br>-Time taken to reach to the destination.<br>-EEOI |

Taking advantages of the technology sophistication in present time and by making use of the computer program available which use accurate information such as weather, shallow water area, sea currents and other related information, the optimum route to be taken by the personal in charge on board of the ship can be determined. The information and modern technologies can help in decision making if they have more than one route to choose in order to arrive to specific destination. The criteria for the route selection are to achieve minimal fuel consumption, ship emission and time taken to arrive to the destination.

Besides using computer programs, some companies today make use weather forecast charts and hand the final decision to be made by the personnel in charge. The personnel needs to choose the most appropriate route to avoid bad weather, and if a wrong decision is made, this may cause a delay on the ship voyage and the ship will be unable to arrive at estimated time arrival (ETA). The main reasons of avoiding a route with bad weather are for safety of the vessel, its property, fuel and cargo, as well as to reduce emission.

Jeppesen, a Boeing company, had launched the Vessel and Voyage Optimization Solution (VVOS). VVOS is one of the weather routing software used in order to determine the best ship route.

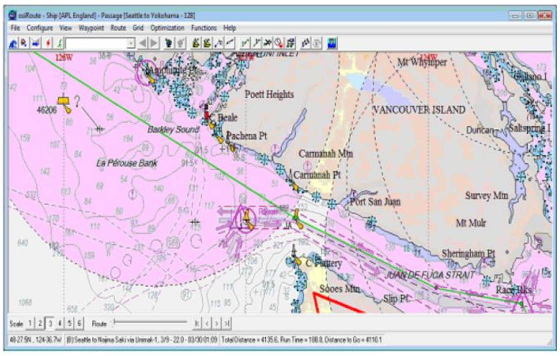


Figure 1: Route plotted on a navigation chart using Jeppesen C-Map Professional Chart [3]

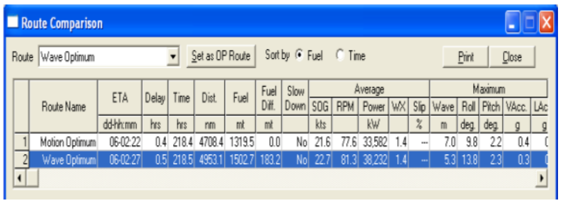


Figure 2: Ship routes comparison by using VVOS [3]

Figure 1 shows the example of ship route plotted on a navigation chart using Jeppesen C-Map Professional Chart, while Figure 2 shows the comparison between ship routes developed by using VVOS [3]. The personnel in charge on board of the ship can use the aid of the software such as VVOS or other weather routing software to decide the best route. The implementation of weather routing optimisation on board the ship can reduce the fuel oil consumption by 2 – 4 % [4].

#### Implementation

The concept of how weather routing software determines the best route takes into consideration four different parameters, which are distance sailed, speed of the vessel, condition of the sea and EEOI. Nevertheless, in real life situation, the software takes into consideration more than four parameters. Due to lack of information and data, only four parameters on concept of the weather routing optimisation below are explained in this paper.

**a) Different Weather Condition with Almost the Same Speed and Distance Sailed**

As show in Table 1 above, in order to evaluate the weather routing optimization technically, the voyage data for steam propulsion LNG carrier including fuel consumption, speed and distance sailed of the ship at different sea condition are required. For this project, the voyage data were collected from the previous work described in [2], and shown in Tables 2, 3 and 4[2].

**Table 2: Different Weather Condition with about the Same Speed and Distance**

| | Report Date | HFO cons.(tonnes) | Boil Off Cons. (tonnes) | Distance Sailed(Nm) | Speed (Knot) | EEOI |
|---|---|---|---|---|---|---|
| | 1/17/2013 | 43 | 121.0 | 401.0 | 18 | 20.606 |
| | 1/31/2013 | 25 | 120.0 | 403.0 | 18.2 | 17.879 |

**Table 3: Different Weather Condition with About the Same Speed and Distance**

| | Report Date | HFO cons.(tonnes) | Boil Off Cons. (tonnes) | Distance Sailed(Nm) | Speed (Knot) | EEOI |
|---|---|---|---|---|---|---|
| | 1/18/2013 | 57 | 122.0 | 410.0 | 17.9 | 21.662 |
| | 2/26/2013 | 33 | 123.0 | 410.0 | 17.8 | 18.871 |

**Table 4: Different Weather Condition with About the Same Speed and Distance**

| | Report Date | HFO cons.(tonnes) | Boil Off Cons. (tonnes) | Distance Sailed(Nm) | Speed (Knot) | EEOI |
|---|---|---|---|---|---|---|
| | 1/1/2013 | 64 | 116.0 | 428.0 | 18.2 | 20.505 |
| | 6/9/2013 | 18 | 131.0 | 430.0 | 18.1 | 16.437 |
| | 7/13/2013 | 14 | 133.0 | 431.0 | 18 | 16.28 |
| | 7/14/2013 | 13 | 134.0 | 430.0 | 17.9 | 16.339 |

The red and purple columns in Table 2, 3 and 4 represent the weather condition of each of the route taken by the ship, as illustrated in Figure 3.

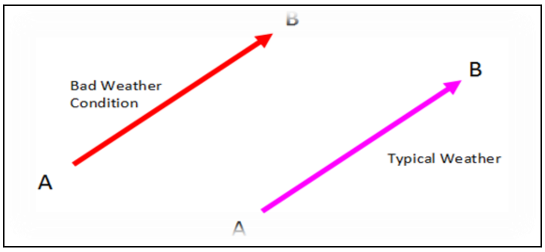


**Figure 3: Weather Condition of Route A and B**

Tables 2, 3 and 4 illustrate that the fuel consumption of a ship taking a route with bad weather condition is higher as compared to a ship sailing on the route with normal weather condition with the same speed and distance sailed. Table 5 shows similar distance sailed and speed of the ship but with different weather condition. A ship taking the route with bad weather condition consumes 177 tonnes of both heavy fuel oil and boil off gas, which is 21 tonnes higher as compared to the other route. Due to higher fuel consumption rate, its EEOI becomes higher because EEOI is directly proportional to fuel consumption.

**b) Different Weather Condition and Distance Sailed with Almost the Same Speed**

In real life situation, although with implementation of weather routing optimization as an approach to reduce fuel consumption and emission, the distance sailed by a ship sailing on a typical weather condition will be greater than the route with bad weather condition because it needs to avoid the bad weather condition (Figure 4).

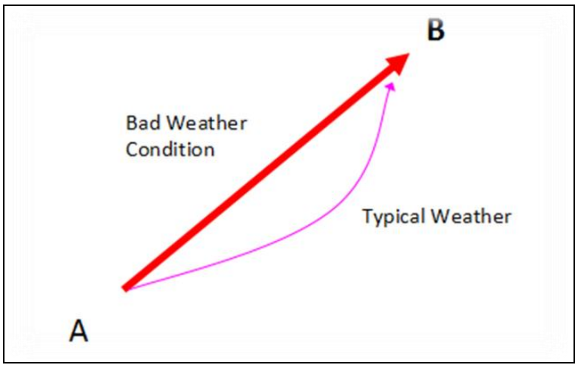


**Figure 4: Route taken by Ship in Weather Routing Optimization**

A voyage data of the steam propulsion LNG carrier with different weather condition and different distance sailed but the same speed are obtained in order to evaluate this situation as shown in Tables 5, 6 and 7.

**Table 5: Different Weather Condition and Distance Sailed with About the Same Speed and Distance**

| | Report Date | HFO cons.(tonnes) | Boil Off Cons. (tonnes) | Distance Sailed(Nm) | Speed(Knot) | EEOI |
|---|---|---|---|---|---|---|
| | 1/17/2013 | 43 | 121.0 | 401.0 | 18 | 20.606 |
| | 1/28/2013 | 38 | 126.0 | 439.0 | 18 | 19.609 |
| | 6/9/2013 | 18 | 131.0 | 430.0 | 18.1 | 16.437 |

**Table 6: Different Weather Condition and Distance Sailed with About the Same Speed and Distance**

| | Report Date | HFO cons.(tonnes) | Boil Off Cons. (tonnes) | Distance Sailed(Nm) | Speed(Knot) | EEOI |
|---|---|---|---|---|---|---|
| | 1/18/2013 | 57 | 122.0 | 410.0 | 17.9 | 21.662 |
| | 2/12/2013 | 31 | 128.0 | 428.0 | 17.88 | 19.054 |
| | 5/27/2013 | 11 | 124.0 | 420.0 | 17.9 | 15.034 |
| | 7/14/2013 | 13 | 134.0 | 430.0 | 17.9 | 16.339 |
| | 11/26/2013 | 12 | 135.0 | 425.0 | 17.9 | 16.931 |

Tables 5 and 6 illustrate that the fuel consumed for a route with a bad weather condition is higher although the distance sailed by the ship with typical weather condition is greater. From EEOI point of view, due to the higher fuel consumption, the EEOI of route with bad weather condition is greater as compared to the other route.

## Monitoring

Energy Efficiency Operational Indicator (EEOI) is a tool used to monitor the effect of implementing weather routing optimisation on steam propulsion LNG carrier. Assuming that the base ship implements weather routing optimisation and the fuel consumption is reduced by 3% for every voyage, based on the voyage profile data obtained from the previous data [6], the average EEOI and fuel consumption for every voyage can be calculated as shown in Table 7.

Table 7: Total fuel consumption by eighteen voyages and the average EEOI

| | without WRO | | with WRO | | | |
|---|---|---|---|---|---|---|
| Voyage | ∑HFO Consume (tones) | EEOI (×10-6) tons.CO2/ tons.NM | ∑HFO Consume (tones) | EEOI (×10-6) tons.CO2/ tons.NM | Different In ∑HFO Consume (tones) | Reduce avg EEOI (%) |
| **1** | 725 | 43.665 | 703.25 | 43.013 | 21.75 | 1.49 |
| **2** | 769 | 39.414 | 745.93 | 38.821 | 23.07 | 1.51 |
| **3** | 760 | 40.609 | 737.2 | 40.025 | 22.80 | 1.44 |
| **4** | 1446 | 32.471 | 1402.62 | 31.887 | 43.38 | 1.80 |
| **5** | 466 | 36.048 | 452.02 | 35.641 | 13.98 | 1.13 |
| **6** | 323 | 47.259 | 313.31 | 46.803 | 9.69 | 0.97 |
| **7** | 432 | 32.985 | 419.04 | 32.660 | 12.96 | 0.98 |
| **8** | 478 | 37.022 | 463.66 | 36.714 | 14.34 | 0.83 |
| **9** | 473 | 34.460 | 458.81 | 34.111 | 14.19 | 1.01 |
| **10** | 779 | 43.170 | 755.63 | 42.584 | 23.37 | 1.36 |
| **11** | 302 | 55.652 | 292.94 | 55.175 | 9.06 | 0.86 |
| **12** | 422 | 40.419 | 409.34 | 40.072 | 12.66 | 0.86 |
| **13** | 545 | 38.383 | 528.65 | 37.911 | 16.35 | 1.23 |
| **14** | 795 | 37.449 | 771.15 | 36.960 | 23.85 | 1.31 |
| **15** | 464 | 35.812 | 450.08 | 35.404 | 13.92 | 1.14 |
| **16** | 649 | 40.189 | 629.53 | 39.816 | 19.47 | 0.93 |
| **17** | 785 | 56.933 | 761.45 | 56.193 | 23.55 | 1.30 |
| **18** | 760 | 40.609 | 737.2 | 40.025 | 22.80 | 1.44 |
| | | | | | **341.19** | **1.20** |

Table 7 shows the total fuel consumption and average EEOI for eighteen voyages in one year. From the table, it can be concluded that by implementing weather routing on board of steam propulsion LNG carrier, the total fuel consumed per year is 341.19 tonnes while percentages of average EEOI reduced is 1.2 % per year. This information indicates that the average EEOI per voyage as well as ship's emission is reduced by 1.2%.

## Asymmetry Pre-Swirl Stator

The steps to implement asymmetry pre-swirl stator on steam propulsion LNG carrier are described in the subsection of this chapter.

### Planning

The parameters for SEEMP evaluation on steam propulsion LNG carrier for Asymmetry pre-swirl stator are summarized in Table 8.

Table 8: Asymmetry Pre-Swirl Stator Parameters

| Ship-Specific Measures | Primary Parameters | Secondary parameters |
|---|---|---|
| Assymetry pre-swirl stator | -Reduce delivered power need for the ship to run at same speed by (5.29 % for constant pitch, 6.98 % for variable pitch) | -power delivered (Pd)<br>- Efficiency.<br>-EEOI |

LNG carrier is classified by its LNG storage tank of some standard capacities such as 140,000, 160,000, 180,000 and 200,000 $m^3$. The simplified form to this classification is through 160k LNG carrier for an example of LNG carrier that consist 160,000$m^3$ tank of gases. From the experiment conducted on 160k LNG carrier model ship at Pusan National University, the model setup, ship particulars and results obtained in the experiment are as follows [5].

Figure 5: Ship Model

Figure 6: Ship model without Asymmetry Pre-Swirl Stator

Figure 7: Ship model with Asymmetry Pre-Swirl Stator

Table 9: Ship Model Particulars

| Dimension | Ship | Model |
|---|---|---|
| **LPP (m)** | 278 | 5.756 |
| **LWL (m)** | 274.1 | 5.675 |
| **B (m)** | 46 | 0.952 |
| **T(m)** | 11.6 | 0.24 |
| **Design Speed(Knot)** | 19.5 | 2.81 |
| **λ** | 48.3 | |

Table 10: Result of the experiment

| Dimension | PD(Kw) | ΔPD (%) |
|---|---|---|
| **Without Asymmetry Pre-Swirl Stator** | 26438 | 0 |
| **With Asymmetry Pre-Swirl Stator (Constant)** | 25038 | -5.29 |

By referring to the result of this experiment in Table 10, it can be concluded that the delivered power (PD) of 160k LNG carrier can be reduced by implementing the constant type Pre-Swirl Asymmetry Stator. The delivered power (PD) can be reduced up to -5.29 %. In this project, the constant Asymmetry Pre-Swirl Stator has been installed on the base ship, with assumption that the hull form of the basis ship is the same as the 160k LNG carrier model used in the above experiment.

## Implementation

By using the data of the base ship of LNG carrier, the fuel consumption can be calculated. The results of the calculation are as shown below.

Table 11: Effect of Implementing Asymmetry Pre-Swirl Stator on the Base Ship

| Items | Without | With |
|---|---|---|
| **PD(Kw)** | 26800 | 25382.28 |
| **Steam** | 87.6 | 84.17 |
| **Fuel** | 8.28 | 7.84 |
| **Δ Fuel Consumption Rate** | 5.31 % | |

Table 12 shows that the total fuel consumption rate is reduced by 5.31 % when asymmetry pre-swirl stator is installed on the base ship. By using the voyage profile data obtained from the previous thesis written by Tan Wei Chieh entitled Implementing Energy Efficiency Operational Indicator (EEOI) on LNG carrier, the total fuel consumption for one year and EEOI after implementing asymmetry pre-swirl stator can be calculated. The total fuel consumption and average EEOI are shown in Table 12.

Table 12: Total Fuel Consumption per Year

| | Without asymmetry Pre-Swirl Stator | | | With asymmetry Pre-Swirl Stator | | | Different |
|---|---|---|---|---|---|---|---|
| Monthly Breakdown | Total Fuel Consumed | | | Total Fuel Consumed | | | |
| | ∑HFO (tones) | ∑MDO (tones) | ∑BOG (tones) | ∑HFO (tones) | ∑MDO (tones) | ∑BOG (tones) | ∑HFO (tones) |
| Jan | 1678 | 0 | 2162 | 1588.90 | 0 | 2162 | 89.10 |
| Feb | 1435 | 0 | 1743 | 1358.80 | 0 | 1743 | 76.20 |
| Mar | 1919 | 30 | 1630 | 1817.10 | 30 | 1630 | 101.90 |
| May | 703 | 32 | 1510 | 666.62 | 32 | 1510 | 36.38 |
| June | 882 | 2 | 1755 | 783.09 | 2 | 1755 | 98.91 |
| July | 1062 | 21 | 2190 | 965.84 | 21 | 2190 | 96.16 |
| Aug | 1054 | 0 | 1494 | 884.40 | 0 | 1494 | 169.60 |
| Sept | 675 | 0 | 1895 | 633.48 | 0 | 1895 | 41.52 |
| Oct | 1519 | 20 | 2186 | 1335.13 | 20 | 2186 | 183.87 |
| Nov | 740 | 0 | 2393 | 689.34 | 0 | 2393 | 50.66 |
| Dec | 1578 | 0 | 2034 | 1493.26 | 0 | 2034 | 84.74 |
| | | | | | | | **1029.04** |

Table 12 above indicates that by implementing the asymmetry pre-swirl stator on steam propulsion LNG carrier, the total fuel consumption can be reduced to 1029.04 tonnes per year.

## Monitoring

Energy Efficiency Operational Indicator (EEOI) is a tool used to monitor the effect of implementing asymmetry swirl-stator on steam propulsion LNG carrier. The fuel consumption rate can be reduced by 5.31 %. By applying the value into the voyage profile data obtained [5], the Average EEOI for every month and for one year can be obtained. The results from the calculation are shown in Table 13.

Table 13: Average EEOI without asymmetry pre-swirl stator for one year [5]

| Without Asymmetry Pre-Swirl Stator | | | |
|---|---|---|---|
| Monthly Breakdown | Total Transport Work (t. NM) | Total Emission (tones) | EEOI average ( $\times 10^{-6}$) tons.$CO_2$/ tons.NM |
| **January** | 322484207 | 11171 | 34.6 |
| **February** | 218043390 | 9262 | 42.51 |
| **March** | 214074982 | 8736 | 40.81 |
| **May** | 189969806 | 6600 | 34.74 |
| **June** | 146847269 | 7573 | 51.57 |
| **July** | 294254201 | 9397 | 31.94 |
| **August** | 82147870 | 7080 | 86.18 |
| **September** | 223289587 | 7313 | 32.75 |
| **October** | 258866002 | 10806 | 41.75 |
| **November** | 260472576 | 8885 | 34.11 |
| **December** | 229232112 | 10508 | 45.84 |
| | ***2439682002*** | ***97334*** | **40.54** |

Table 14: Average EEOI with asymmetry pre-swirl stator for one year

| With Asymmetry Pre-Swirl Stator | | | |
|---|---|---|---|
| Monthly Breakdown | Total Transport Work (t. NM) | Total Emission (tones) | EEOI average ( $\times 10^{-6}$) tons.$CO_2$/ tons.NM |
| **January** | 322484207 | 10893.96 | 33.78 |
| **February** | 218043390 | 9025.10 | 41.39 |
| **March** | 214074982 | 10042.68 | 46.91 |
| **May** | 189969806 | 6228.61 | 32.77 |
| **June** | 146847269 | 7069.84 | 48.14 |
| **July** | 294254201 | 8659.26 | 31.23 |
| **August** | 82147870 | 6557.64 | 79.83 |
| **September** | 223289587 | 7164.90 | 32.41 |
| **October** | 258866002 | 10026.63 | 38.74 |
| **November** | 260472576 | 8592.89 | 32.99 |
| **December** | 229232112 | 9479.61 | 41.35 |
| | ***2439682002*** | ***93741.13*** | **38.42** |

Table 13 and Table 14 show the comparison of average EEOI value for one year. From the table, it can be concluded that the implementation of asymmetry pre-swirl stator can reduce the average EEOI for one year by 5.23 %. Personnel in charge is responsible to ensure the average EEOI is almost the same every year after the implementation of asymmetry swirl stator, and the value should maintain at 38.42 × $10^{-6}$tons.$CO_2$/ tons. nm. As the ship continues to operate, the hull resistance will increase gradually due to the fouling and barnacles that growth on the surface of the hull, including the asymmetry pre-swirl stator. This situation will lead to the increase of the average EEOI value per year. If the difference in average EEOI per year is too much lower as compared to the average EEOI value per year before the implementation of the asymmetry pre-swirl stator, the ship will need to go for docking in order to undergo hull cleaning process so that the average EEOI and total saving of fuel per year can be maintained.

### Self-Evaluation and Improvement

In this stage, for both weather routing optimisation and asymmetry pre-swirl stator, the monitoring data recorded in monitoring stage will be collected and assembled for further analysis. Analysis is done to deepen the understanding on the overall characteristics of the ship-specific measures that have been implemented on board the ship. The result from the analysis will be used during the evaluation period in order to make improvement during the next cycle of SEEMP. For example, the voyage profile data for the same period for the next year is collected and analysed, and the new average EEOI is calculated. The new average EEOI in one year is then compared with the average EEOI one year before the weather routing optimisation and asymmetry pre-swirl stator were implemented on board the ship. Nevertheless, several conditions might occur, as in Table 15.

**Table 15: Example of data collection and analysis**

| Ship-Specific Measure | Condition |
|---|---|
| **Weather routing optimisation** | If the new average EEOI in one year is less than 5.23% as compared to the average EEOI in one year before, weather routing optimisation is implemented on board the ship. |
| **Asymmetry pre-swirl stator** | If the new average EEOI in one year is less than 5.23% as compare to the average EEOI in one year before, asymmetry pre-swirl stator is implemented on board the ship. |

Table 15 shows the example of the condition that might occur during the self-evaluation and improvement stage of SEEMP. If the conditions occur as stated in the above table for weather routing optimisation and asymmetry pre-swirl stator, respectively, it indicates that the efficiency of each ship-specific measure is reduced and the person in charge should take initial action by identifying the factors that contribute to the condition and figuring out the solution.

## ECONOMIC EVALUATION OF IMPLEMENTING SEEMP

### The Initial Cost Of Steam Propulsion LNG carrier

The initial cost of steam propulsion LNG carrier covers design and construction cost. Base on the thesis written by Siow Chee Loon on Design of High Performance Steam Propulsion LNG carrier, the initial cost are estimate as illustrate in the Table 16.

**Table 16: The details of price for Steam Propulsion LNG carrier [6]**

| Components | Description |
|---|---|
| **Ship Price** | USD 170,300,000 |
| **Size of LNG carrier** | 140,000 $m^3$ |
| **Propulsion, Auxiliary and related equipment.** | USD 32,500,000 |
| **Data Collection** | 2003 |

Table 16 shows the price for the basic items for steam propulsion LNG carrier. The size of the LNG carrier above is about 1.7 % smaller than the base ship of steam propulsion LNG carrier used in this project. Even though they are slightly different in size, the detail above can be applied in this project because the difference in size is insignificant and can be neglected.

### Repair and Maintenance Cost

The data for repair and maintenance cost are illustrated Table 17.

**Table 17 Detail of Repair and Maintenance Cost [6]**

| Components | Description |
|---|---|
| **Number of failure per year** | 10 |
| **Relative repair cost** | 0.5% x ship price |
| **Ship price** | USD 170,300,000 |
| **Repair cost per failure** | USD 851,500 |
| **Annual repair cost** | USD 8,851,000 |

Table 17 indicates that the annual repair and maintenance cost for steam propulsion LNG carrier is USD 8,851,000. The repair and maintenance cost is assumed to be the same for both conditions, before and after the implementation of SEEMP on board the steam propulsion LNG carrier.

## Operating Cost

The operating cost is assumed to be the same as the conventional steam propulsion's operating cost which is USD 83,325,680 per year [6].

### Fuel Cost

Fuel cost per year is calculated based on the voyage data for one year and the result of the calculation is shown in Table 18.

Table 18: Fuel Cost for Conventional Steam Propulsion LNG carrier [6]

| Distance between port | 3500 n.m |
|---|---|
| **Ship speed** | 19.5 knots(service) |
| **Sailing time/sail** | 179.5 hours(7.5 days) |
| **Loading/unloading times** | 12 hours |
| **Times per round trips** | 383 hours(16 days) |
| **Services day/year** | 355 |
| **Total round trip per year** | 22 |
| **Fuel price** | 361 – 406 USD/ ton (select 384 USD/ton) [7] |
| **BOG + Fuel oil consumption** | 3.838 tons/hours |
| **Fuel consumption per trip** | 2064 tonnes/trip |
| **Fuel cost per trip** | 792,576 USD |
| **Fuel cost per year** | 17,436,672 USD |

As stated in Table 18, the total fuel cost per year for steam propulsion LNG carrier is 17,436,672 USD.

## Salvage Value and Income per year

The salvage value and total income per trip are as shown in Table 19. The calculation is based on the total typical number of trip of the steam propulsion LNG carrier which is 22.

Table 19: Salvage Value and income per year [6]

| Total trip per year | 22 |
|---|---|
| **Income per trip** | 4,474,369 USD |
| **Income per Year** | 98,436,118 USD |
| **Salvage Value** | 20,704,504 USD |

### Economic Evaluation of Implementing SEEMP on Weather Routing Optimisation

The net present value (NPV) for both steam propulsion LNG carrier with and without weather routing optimisation on board of the ship have been calculated. The purpose of calculating NPV for both conditions is to determine which condition would give more profit in term of investment. The calculations of NPV for both conditions are shown in Appendix F while the results from the calculation are shown in Table 20 and Figure 7 below.

Table 20: Comparison between Net Present Values (NPV)

| i (%) | NPV (without) Million USD | NPV (with) Million USD |
|---|---|---|
| **0.25** | 1222.73 | 1225.35 |
| **1.00** | 1116.18 | 1118.60 |
| **2.00** | 990.86 | 993.05 |
| **3.00** | 882.04 | 884.03 |

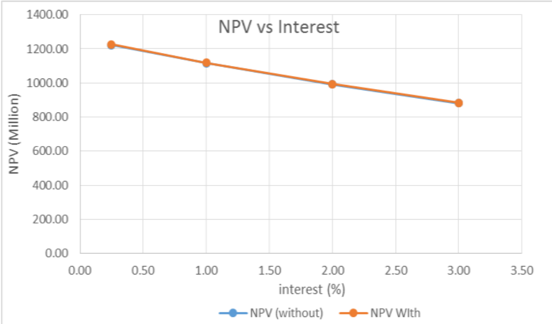


Figure 7: Graph of comparison of NPV between steam propulsion LNG carrier with and without weather routing optimisation

Table 20 and Figure 7 show the comparison between net present value (NPV) of steam propulsion LNG carrier with and without weather routing optimisation on board of the ship. From Figure 7, the NPV for steam propulsion LNG carrier with weather routing optimisation is more compared to steam propulsion LNG carrier without weather routing optimisation. This indicates that the implementation of weather routing optimisation is more profitable. However, the value of NPV decreases linearly as the interest increases. This situation proves that the profit received by implementing this ship-specific measure on board steam propulsion LNG carrier decreases and approaches zero as the interest increases.

## Economic Evaluation of Implementing SEEMP on Asymmetry Pre-Swirl Stator

The net present value (NPV) for both steam propulsion LNG carrier with and without asymmetry pre-swirl stator have been calculated. The purpose of calculating NPV for both conditions is to determine which condition would give more profit in term of investment. A higher NPV value indicates that the condition or investment is more profitable, as shown in Table 21 and Figure 8.

Table 21: Comparison between Net Present Values (NPV)

| i (%) | NPV (without) Million USD | NPV (with) Million USD |
|---|---|---|
| **0.25** | 1222.73466 | 1230.52866 |
| **1** | 1116.18255 | 1123.40095 |
| **2** | 990.85575 | 997.39615 |
| **3** | 882.03714 | 887.98794 |

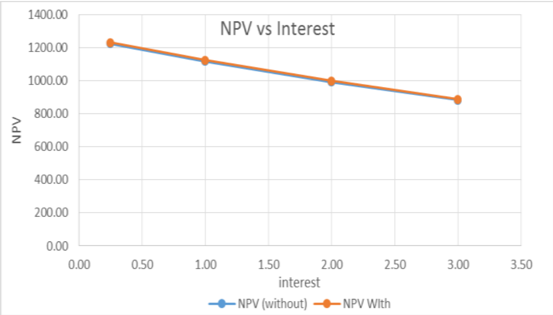


Figure 8: Graph of comparison of NPV between steam propulsion LNG carrier with and without asymmetry pre-swirl stator

Table 21 and Figure 8 show the comparison between the net present value (NPV) of steam propulsion LNG carrier with and without asymmetry pre-swirl stator. From Figure 8, the NPV for steam propulsion LNG carrier with asymmetry pre-swirl stator is higher as compared to steam propulsion LNG carrier without asymmetry pre-swirl stator. This information indicates that the implementation of asymmetry pre-swirl stator is more profitable. However, the value of NPV decreases linearly as the interest increases. This situation proves that the profit received by implementing this device on board of steam propulsion LNG carrier decreases and approaches zero as the interest increases.

## Discussion

### Technical Evaluation

In this project, the technical evaluation is focused on the effect of implementing ship-specific measure, such as weather routing optimisation and asymmetry pre-swirl stator on steam propulsion LNG carrier, in terms of fuel consumption and EEOI. Implementation of weather routing optimisation on board the ship can reduce the total fuel consumption by 341.19 tonnes per year, as referred to the basic formulae of EEOI in Equation 1.

$$EEOI = \frac{\sum_j FC_j . CF_j}{m_{cargo} . D} \quad (1)$$

Fuel consumption is proportional to EEOI. In short, when fuel consumption reduces, the EEOI will decrease. From the result of the calculation of the average EEOI per year in the previous chapter, average EEOI per year can be reduced by 1.2 % after weather routing optimisation is implemented. This indicates that the emission level of the steam propulsion LNG carrier in term of $CO^2$ production per cargo tonne-nautical mile can be reduced.

In comparison, for asymmetry pre-swirl stator, the total fuel consumption and percentage of average EEOI reduce per year are 1029.04 tonnes and 5.23%, respectively.

In short, the implementation of both ship-specific measures gives benefits in technical part, in term of total fuel consume and average EEOI reduce per year, while the implementation of asymmetry pre-swirl stator on board the ship gives more benefits compared to the weather routing optimisation.

### Economic Evaluation

In this study, economical evaluations have been done for both implementation of weather routing optimisation and asymmetry pre-swirl stator. The results show that the net present value of both implementations is higher compared to the net present value of steam propulsion without weather routing optimisation and asymmetry pre-swirl stator implemented on board the ship. This situation indicates that the investment made on the implementation of both ship-specific measures is profitable. The payback period for implementation of weather routing optimisation is 2.33 years while the payback period for asymmetry pre-swirl stator is 2.32 years.

The economic evaluation of this project is incomplete because this project does not take into account the cost per year of using the service of weather routing optimisation such as weather routing software, weather forecast, installation cost of asymmetry pre-swirl stator, maintenance and salvage cost of asymmetry pre-swirl stator due the lack of data and information. In order to complete the economic evaluation, the required data need to be identified so that the actual value of net present value and payback period can be calculated.

## CONCLUSION

The project has been completed by firstly identifying the approach in order to improve the typical steam propulsion LNG carrier efficiency in terms of reducing the ship's emission and EEOI. After identifying the approach that is possible to be implemented on board of the ship, the parameters in order to implement SEEMP are determined. The next step is to follow the guidelines published by IMO, MEPC.213 (63) regarding the development of Ship Energy Efficiency Management Plan (SEEMP). There are four main stages in developing SEEMP which are planning, implementing, monitoring and self-evaluation. The entire steps have been tested for weather routing optimisation and asymmetry pre-swirl stator.

Technical evaluation of implementing weather routing optimisation and asymmetry pre-swirl stator has been discussed extensively in this paper. The technical evaluation in this project takes into consideration the fuel consumption and EEOI after the plan has been executed. In comparison, the economic evaluation has been assessed by using the net present value in order to determine which condition is more profitable.

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