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Optimization of the Energy Efficiency Operational Indicator for M/V NSU JUSTICE 250,000 DWT by Grey Relational Analysis Method in Vietnam

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Abstract

The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), Annex VI with new Chapter 4 entitled with "Regulations on Energy Efficiency for Ships" has made effectively then enforcing all ships must follow regulations in aims with the energy efficiency in operating ships and reducting the environmental pollution. In this article, the calculation of the Energy Efficiency Operational Indicator EEOI has been conducted under the guidelines for voluntary use of the ship energy efficiency operational indicator of the International Maritime Organization (IMO), MEPC.1/Circ.684 adopted on 17 August 2009. The Grey Relational Analysis (GRA) method has been studied and applied in this research in order to optimize the energy efficiency for M/V NSU JUSTICE 250,000 DWT in the shipping transportation company, Vietnam. These results collected will be identified that the energy efficiency of ships achieves then the decreasing fuel consumption of engine and optimizing the routes of a certain ship. Besides that, this research is fundamental to these next studies about the energy efficiency of ships.

Keywords: Energy efficiency of ships; Grey relational analysis; MARPOL 73/78; EEOI; Bulk carriers

1. Introduction

The increase of carbon dioxide CO_2 emission into the environment has lead to the big problem of the environmental pollution especially the greenhouse gas effects. The greenhouse gas emissions make the global warming potential, melting glaciers, or rising sea levels nowadays. This phenomenon has affected negatively to human and creature in the planet. So, they need to restrict and reduce the carbon dioxide CO_2 emission from actives and economical development at each nation.

The International Maritime Organization (IMO) with Marine Environment Protection Committee (MEPC 67) has approved the document of the third IMO GHG Study 2014. In where, it provides the updated emission estimates about greenhouse gas emissions from ship operational activities. This research also indicates the certain statistic about carbon dioxide CO_2 emissions from shipping transportation industries. In particular, the international shipping transportation [8] emitted 796 million tonnes of carbon dioxide CO_2 in 2012 corresponding to 2.2% of the total carbon dioxide emissions from other industries. On the other hand, the global economic downturn, the international shipping transportation has estimated to emit 885 million tonnes of carbon dioxide CO_2 that was 2.8% of the total global CO_2 emissions for that year.

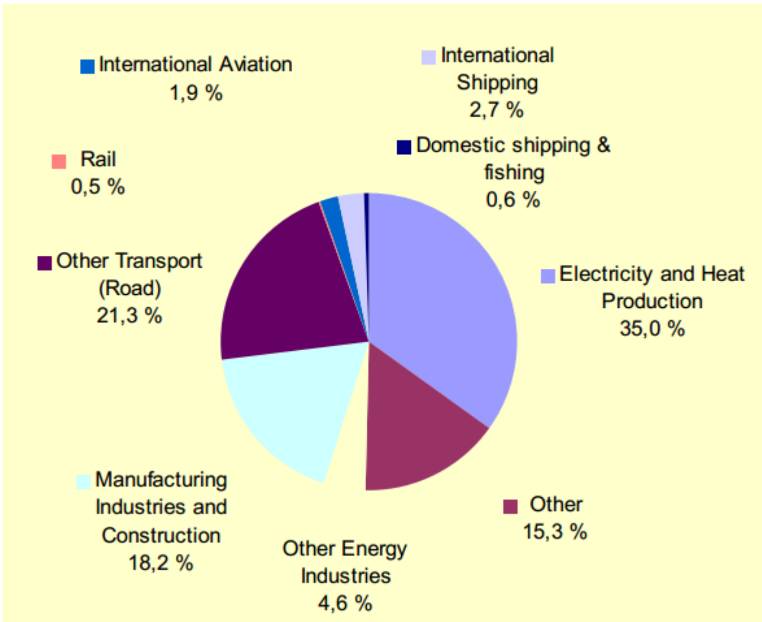

Figure 1: Carbon dioxide CO_2 emissions from shipping transportation with total global emissions [8].

One another side, Marine Environment Protection Committee (MEPC) has given extensive consideration to control of GHG emissions from ships and to the year of 2009, a component of specific technical and operational reduction measures. In particular, the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), Annex VI, Chapter IV has regulated about the energy efficiency for ships. The Energy Efficiency Design Index (EEDI) for new ships, the Energy Efficiency Operational Indicator (EEOI) for the existing ships and the Ship Energy Efficiency Management Plan (SEEMP) is an operational measure that establishes a mechanism to improve the energy efficiency of ships.

The Grey Relation Analysis (GRA) method was formulated by Ju-long Deng in 1982. In where, a white system is defined when the internal message such as architecture, operation mechanism, system characteristics and parameters are completely known. On the other hand, if one cannot obtain any information and characteristics about the system, then it is a black system. Grey space is thus a system defined between the white system and black system. In a result, the minimal database requirement, simplicity of use and reasonably expected results are the advantages of the grey system over the traditional regression analysis. The Grey Relation Analysis (GRA) has been applied to various fields that relating to the energy efficiency. For instance, [12] used a dynamic grey model to examine the annual load demand of the power system in Japan, and they concluded that the grey system for the long-term load forecasting problem had a higher accuracy than the linear single regression model. The interrelationships among energy consumption, energy-related CO_2 emission and economic growth of 34 industrial sectors in Taiwan were explored by Chang and Lin [1]. They found that industrial production had the strongest relationship with CO_2 emission and the economy in Taiwan relied heavily on CO_2 intensive industries. Liang [9] used GRA to capture the preliminary schedules for the short-term hydro-electric generation scheduling of a power system and found that hydro schedules generated by the GRA approach were close to the optimal demands predicted by the differential dynamic programming method. Hu and Yang [6] described the attenuation pattern of solar radiation intensity on sunny days by combining a definitive physical model with grey parameters. Shi MJ et al. [11] had applied the Grey Relational Analysis in field of energy efficiency assessment for pump station.

Methodological and theoretical advances in grey theory have been developed in recent years. Deng [4] proposed detailed information about the definition of synthesizing kenning mode and the theorem of grey hazy set including embryo, growing, mature and evidence subsets. The combination of a residual modification model with an artificial neural network sign estimation was proposed by Hsu and Chen [7] to improve the predictive reliability and accuracy of the original GM (1,1) model. Mao and Chirwa [13] examined motor vehicle fatality in USA and UK by the grey prediction theory and found that the GM (1,1) model plus a 3-point average technique had high feasibility, efficiency and accuracy. Lin et al. [10] adopted GRA to construct a dynamic network to analyze the correlations and performances of the industrial productivity, aggregate energy consumption, and the use of fuel mix relate to industrial CO_2 emission changes.

The Grey theory can provide a solution of a system in which the model is unsure or the information is incomplete [3]. Besides that, the Grey theory system can be provided an efficient solution to the uncertainty, multi-input and discrete data problem. On the other hand, the relationship between machining parameters and performance can be found in the Grey Relational Analysis (GRA) theory. In a result, the grey relational grade will utilize the discrete measurement method to measure the distance.

In general, the advantage of the Grey Relational Analysis (GRA) method is that it is designed to study uncertainty. Grey Relational Analysis theory is superior to other methods in field of theoretical analysis of systems with uncertain information and incomplete data experimental. Furthermore, it can be used if the experimental data collected is not supplemental or in case of the researchers does not sure that their experimental data collected is representative. On the other hand, it can be used in early effective factor assessment. However, having a limited number of researches referred in field of shipping transportation especially applying the Grey Relational Analysis (GRA) theory for energy efficiency of ships. Fong-Yuan Ma [5] has researched about the energy efficiency for bulk carrier that using grey relation method but in his research still had some drawbacks about analyzing the energy efficiency of ships. So, in this article, the author has conducted to research about energy efficiency operational indicator, EEOI by applying the Grey Relational Analysis (GRA) for M/V NSU JUSTICE 250,000 DWT of the shipping transportation company in Vietnam. This research included these sections in where section 1, Introduction; section 2, Energy Efficiency Operational Indicator; Section 3, Grey Relational Analysis; section 4, Case study; section 5, Results and discussion, and section 6, Conclusion.

2. Energy Efficiency Operational Indicator

Energy Efficiency Operational Indicator, EEOI is operational measure that is established by International Maritime Organization – IMO following the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) in particular Annex VI for Prevention of Air Pollution from Ships. The Conference of Parties to the International Convention for the Prevention of Pollution from Ships was happened in 1973 and modified by the Protocol in 1978 (MARPOL 73/78). This conference held from 15^{th} to 26^{th} September 1997 in conjunction with the Marine Environment Protection Committee's fortieth session, adopted Conference resolution 8 on CO_2 emissions from Ships.

IMO Assembly resolution A.963(23) on IMO policies and practices related to the reduction of greenhouse gas emissions from ships urged the Marine Environment Protection Committee (MEPC) to identify and develop the mechanism or mechanisms needed to achieve the limitation or reduction of Greenhouse Gas (GHG) emissions from international shipping and in doing so to give priority to the establishment of a GHG baseline and the development of a methodology to describe the GHG efficiency of a ship in terms of GHG emission indicator for that ship [8].

The EEOI index is presented for the energy efficiency of the ship operation over a consistent period which describes trading pattern of the vessel. On the other hand, IMO (International Maritime Organization) also indicated that in order to establish the EEOI (Energy Efficiency Operational Indicator) needs following steps below:

- Define the period for which the EEOI is calculated*
- Define data sources for data collection
- Collect data
- Convert data to appropriate format, and
- Calculate EEOI.

(*Ballast voyages, as well as voyages which are not used for transport of cargo, such as voyage for docking service, should also be included. Voyages for the purpose of securing the safety of a ship or saving life at sea should be excluded.)

Furthermore, the data recording method is used so that experimental data is collected and analyzed to facilitate the extraction of the required information. The experimental data must include: distance traveled, quantity of fuel used; kind of fuel used. All fuel used information may affect the amount of carbon dioxide emitted into the environment. For instance, the fuel information is provided on the bunker delivery notes that regulated under Regulation 18 of

MARPOL 73/78 Annex VI. On the other hand, the unit used for distance traveled and quantity of fuel should be expressed in nautical miles and metric tonnes. It is necessary to provide the significant information that is collected from experimental data of ship with regard to fuel type and quantity, distance traveled and cargo type so that a realistic assessment can be generated. The distance traveled should be computed following the actual voyages and it is saved on Ship's Log-Book.

The calculation of EEOI index following Equation 1 below:

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

Rolling average of EEOI equation following Equation 2:

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

Where:- j: is the fuel type; i: is the voyage number; FCij 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 the 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.

The unit of EEOI depends on the measurement of cargo carried or work done, for example: tonnes CO_2/(tonnes.nautical miles), tonnes CO_2/(TEU.nautical miles), tonnes CO_2/(person.nautical miles), etc. The rolling average EEOI is used in the field of calculation of EEOI index in a suitable time period. For instance, six or ten voyages which are agreed as statistically relevant to the initial averaging period. The Equation (2) shows the rolling average EEOI formula with the certain elements. On the another side, the fuel mass to CO_2 mass conversion factor C_F is a non-dimensional conversion factor between fuel consumption measured in gram and CO_2 emission also measured in gram based on carbon content. The value of C_F is as follow:

No.	**Type of Fuel**	**Reference**	**Carbon Content**	**C_F(t-CO_2/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

Table 1: Fuel mass to CO_2 mass conversion factors (C_F).

It is possible to realize that the EEOI value is as smaller as better in the field of energy efficiency of ships at each certain voyage when considering operational condition on sea. On the other hand, the equation (1) and (2) can be established by adapting for a multiple numbers of voyages and an average EEOI value obtains during a period of time.

Energy Efficiency Operational Indicator itself is not mandatory. However, it is a monitoring tool for energy efficiency that implemented measures due to the International Maritime Organization reveals. It is a reason that to perform EEOI calculations would enable for the operators to measure the energy efficiency of ship and to analyze the effect of any modifies in operation such as voyage planning optimization, hull and propeller cleaning, trim optimization.

3. Grey Relational Analysis

3.1 Data preprocessing

Data preprocessing is used to transform the given data sequence into dimensionless data sequence and it involves the transfer of the original sequence to a comparable sequence. Let the original reference sequence and comparability sequence be represented as x0(k) and xi(k), i = 1,2,3, ..., m; k = 1,2,3, ..., n, respectively, where m is the totalnumber of experiment to be considered, and n is the total number of observation data. Data preprocessing converts the original sequence to a comparable sequence. Several methodologies of preprocessing data can be used in Grey Relation Analysis, depending on the characteristics of the original sequence [2, 14, 15]. For the original sequence "the larger the better", the original sequence is normalized as follows [14].

$$x_i(k) = \frac{x_i(k) - \min(x_i(k))}{\max(x_i(k)) - \min(x_i(k))} \qquad (3)$$

For "the smaller the better" characteristics of the original sequence, the original sequence is normalized as follows [14].

$$x_i(k) = \frac{\max(x_i(k)) - x_i(k)}{\max(x_i(k)) - \min(x_i(k))} \qquad (4)$$

In case, if a defined target value, OB, exists, then the original sequence is normalized as follows [14]:

$$x_i\,(k) = 1 - \frac{\left| xi(k) - OB \ \right|}{\max\left\{ \max(x_i(k) - OB, OB - \min(x_i(k)) \right\}} \qquad (5)$$

There is an alternative simple method for normalizing the original sequence where the original sequence is divided by the first value of the sequence i.e. xi(1) as follows:

$$x_i(k) = \frac{x_i(k)}{x_i(1)} \qquad (6)$$

where, xi(k) us the orginal sequence, xi(k) is the sequence after the data preprocessing, max(xi(k)) is the largest value of xi(k) and min(xi(k)) is the smallest value of xi(k).

3.2. Grey relational analysis coefficients and grey relational analysis grades

After the data preprocessing, a grey relational analysis coefficient is calculated using the preprocessed sequences. The grey relational analysis coefficient can be calculated as [14]:

$$\gamma_i(k) = \gamma(x_o(k), x_i(k)) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{oi}(k) + \zeta\Delta_{\max}} \quad (7)$$

and, $0 < \gamma(x_o(k), x_i(k)) \le 1$; where $\Delta_{oi}(k)$ is the deviation sequence of the reference sequence $x_0(k)$ and comparability sequence $x_i(k)$;

$$\Delta_{oi}(k) = \left| x_o(k) - x_i(k) \right| \quad (8)$$

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \left| x_o(k) - x_j(k) \right| \quad (9)$$

$$\Delta \min = \min_{\forall j \in i} \min_{\forall k} \left| x_o(k) - x_j(k) \right| \quad (10)$$

with ζ is the distinguishing coefficient, $\zeta \in [0,1]$.

After calculation of the grey relational analysis coefficients, grey relational analysis grade is calculated using the following relationship [14]:

$$\gamma = \gamma(x_o, x_i) = \sum_{k=1}^{n} \beta_k \gamma(x_o(k), x_i(k)) \text{ where } \sum_{k=1}^{n} \beta_k = 1 \quad (11)$$

The grey relational analysis grade $\gamma(x_o,x_i)$ represents the degree of correlation between the reference and comparability sequences. In case of grey relational analysis grade is equal to 1 then the reference and comparability sequences are identical. In a result, if a particular comparability sequence is more important to the reference sequence than other comparability sequence, the grey relational analysis grade for that comparability sequence and the reference sequence will be exceeded as compared to other grey relational analysis grades. The grey relational analysis is actually a measurement of the absolute value of data difference between the sequences, and can be used to approximate the correlation between the sequences.

4. Case Study

4.1 M/V NSU JUSTICE 250,000 DWT

In Vietnam, the shipping transportation companies have a numerous number of ships with variety of sizes and types. There are a lot of shipping transportation companies where provide vessels and officers responding to develop the transportation business in domestic and international such as VINIC shipping transportation company associates with Vietnam Maritime University, Vietnam; VOSCO shipping transportation company, NISSHO shipping transportation company, etc. In this study, the target ship is used with a certain name M/V NSU JUSTICE 250,000 DWT of VINIC shipping transportation company. This is the biggest bulk carrier of company that operating on international routes. The experimental data has been collected from its operational activities. This vessel operates on the fixed routes between Japan – Australia – Brazil. Table 2 presents these specification parameters of M/V NSU JUSTICE 250,000 DWT.

Figure 2: M/V NSU JUSTICE 250,000 DWT.

In Figure 2 describes general of M/V NSU JUSTICE 250,000 DWT with design parameters show in Table 2 below.

Item	Category	Parameter
1	Vessel name	NSU JUSTICE
2	IMO Number	9441922
3	MMSI	373072000
4	Vessel type	Bulk carrier
5	Gross tonnage	132,868
6	Dead Weight Tonnage (DWT)	250,000
7	Flag	Panama
8	Draught	18 m
9	Speed Recorded (Max/Average)	13.3/10/4 knots
10	Length x Breadth (L × B)	329.95 m × 57 m
11	Year built	2012

Table 2: Specification parameters of M/V NSU JUSTICE 250,000 DWT.

M/V NSU JUSTICE 250,000 DWT is powered by two-stroke main engine, single acting, crosshead, exhaust gas turbo-charged marine diesel engine with engine type of MAN B&W 7S80MC-C (Mark 7). Its maximum continuos rating (MCR): 21,910 kW at the shaft rotational speed of 74.5 rpm. Furthermore, this vessel is powered by three main diesel generators with engine type of 4-stroke, single acting, turbo-charged diesel engine (6N21AL-SV). The maximum continuous rating (MCR) is 880 kW at the respective shaft rotational speed of 900 rpm. On the other hand, this vessel is fitted the fixed pith propeller (FPP) diameter 9.60 m with 4 blades. Especially, the vessel is equipped with a data acquisition system for collecting the experimental data including the performance and navigation data. The performance and navigation data of this vessel with respect to the fuel consumption rates are considered in this study along with navigation conditions impact on ship.

4.2 Calculation of energy efficiency operational indicator

The EEOI calculation has an important position in enhancing the energy efficiency operation index of ships. In this case of study, the target ship is a bulk carrier with certain name M/V NSU JUSTICE 250,000 DWT. The author conducted to choose this type of ship because it is a popular ship that carries a numerous cargo in shipping transportation industry in the world and in particular, Vietnam. On the other hand, it has been chosen completely based on research situation and operational condition of shipping transportation companies in Vietnam.

Item	Voyage N^o	EEOI
1	16A	4.1616E-04
	16B	5.6719E-04
2	17A	4.9504E-06
	17B	5.8613E-06
3	18A	5.0109E-06
	18B	6.2809E-06
4	19A	5.1751E-06
	19B	6.2269E-06
5	20A	5.0054E-06
	20B	5.509E-06

Table 3: EEOI value of M/V NSU JUSTICE 250,000 DWT.

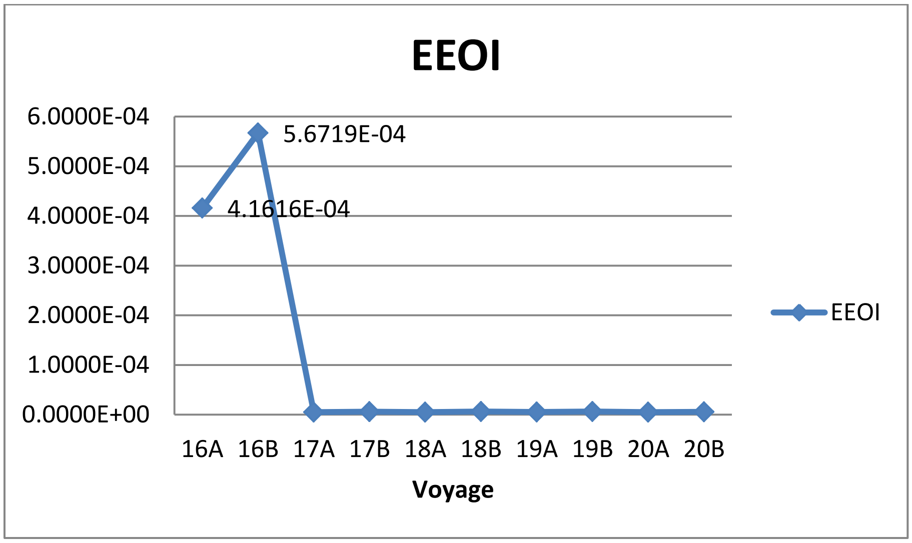

Figure 3: EEOI values for M/V NSU JUSTICE 250,000 DWT.

Throughout the figure 3 above, the Energy Efficiency Operational Indicator (EEOI) at each certain voyage is different. In this study, the recent voyages are used in calculation of EEOI index for M/V NSU JUSTICE 250,000 DWT that this vessel operating. These voyages almost carry bulk ore so there is nothing harmful good affects the carbon dioxide (CO_2) emission to the environment. In addition, it will not impact on the calculation of EEOI index following Equation 1. So, the calculation results above of EEOI index for M/V NSU JUSTICE 250,000 DWT completely depend on the fuel consumption level of main engine.

However, the name of voyage like as Voyage N^{o}16A, N^{o}16B, N^{o}17A, N^{o}17B, N^{o}18A, N^{o}18B, N^{o}19A, N^{o}19B, N^{o}20A, and N^{o}20B is separated from Voyage N^{o}16, N^{o}17, N^{o}18, N^{o}19, and N^{o}20 due to its operational characteristics of routes, time on sea-going and at each port are individual. In fact, the voyage N^{o}16 is total of voyage N^{o}16A and voyage N^{o}16B. In addition, these other voyages are similar like this. So, the value of the Energy Efficiency Operational Indicator (EEOI) at each certain voyage will be represented in Figure 4.

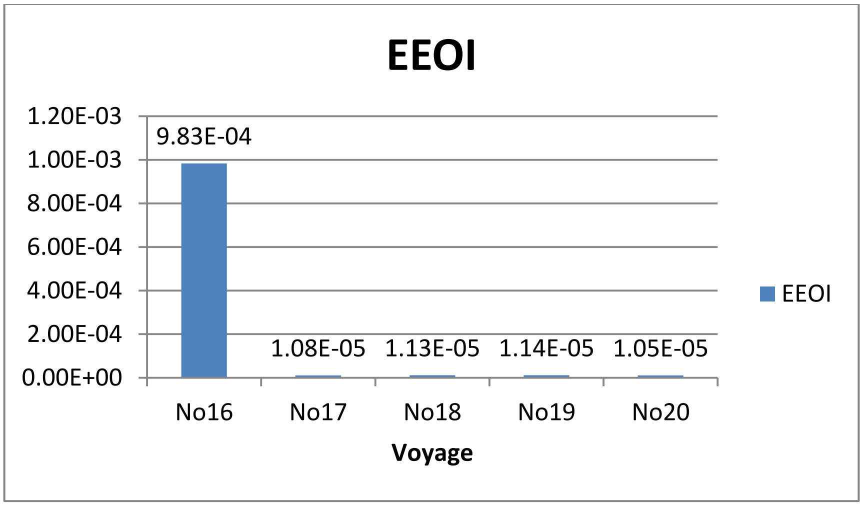

Figure 4: The total of EEOI value at each voyage N^{o}16, N^{o}17, N^{o}18, N^{o}19, N^{o}20.

In figure 4, the maximum EEOI index among these voyages is on Voyage N^{o}16 with 9.83E-04, and the minimum EEOI index is on Voyage N^{o}20 with 1.05E-05. Besides that, these left voyages have also the low values. i.g. EEOI of voyage N^{o}17, N^{o}18, N^{o}19 in turns 1.08E-05, 1.13E-05, 1.14E-05. From these results calculated for M/V NSU JUSTICE 250,000 DWT will be fundamental background to carry out this research.

4.3 Optimization of energy efficiency of M/V NSU JUSTICE 250,000 DWT

In this study, the determination of grey relational analysis grades of experimental data for M/V NSU JUSTICE 250,000 DWT conducted in this section. This is the important working, which is analyzed from the data of voyages. The fundamental calculation is based completely from researching the theory before and referred into section 2.

In the experimental data was collected from the actual voyages of M/V NSU JUSTICE 250,000 DWT when this vessel carried a big amount of cargo traveled around routes between Japan-Australia-Brazil with certain name of voyages. The data of voyages has been taken from Noon-log Record on M/V NSU JUSTICE 250,000 DWT. For instance, the Noon-log Record of a certain Voyage N^{o}16 is showed in Figure 5 below.

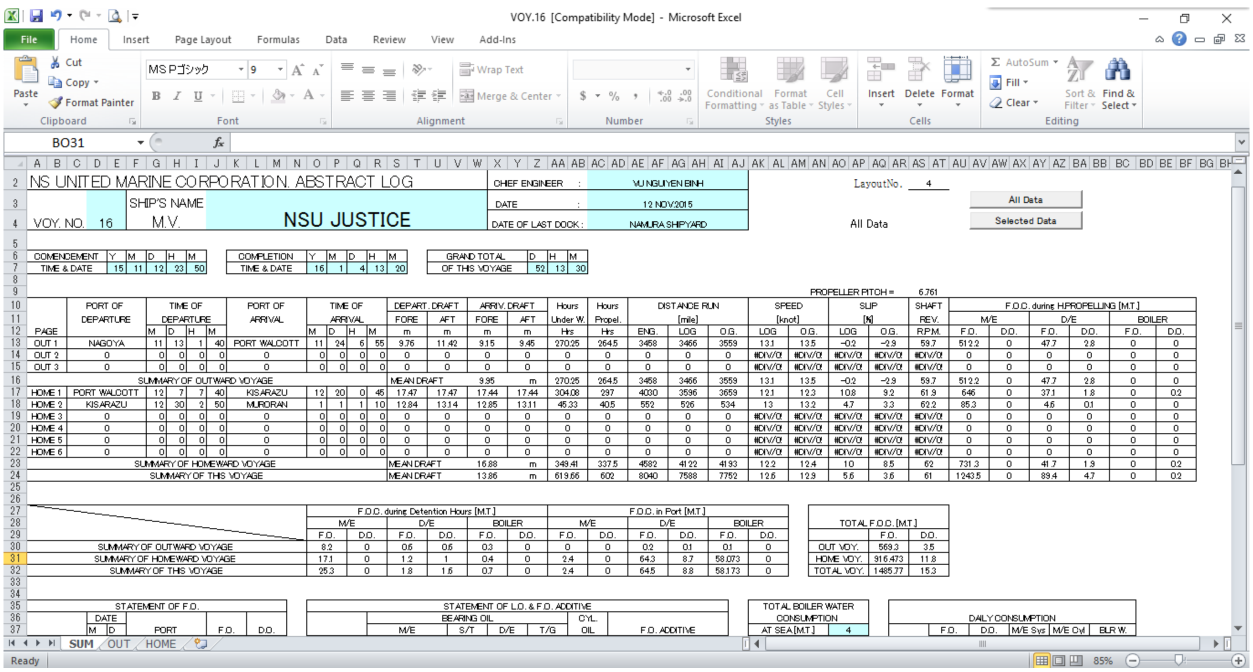

Figure 5: Noon-log Record of Voyage N^{o}16, M/V NSU JUSTICE 250,000 DWT.

In reality, there are five voyages that collected from the experimental data throughout actual travel with names Voyage N^{o}16, N^{o}17, N^{o}18, N^{o}19, N^{o}20 due to n=5. On the other hand, the proof is based on the calculation of EEOI values for voyages as well as aims of this research that reduce the fuel consumption of engine on M/V NSU JUSTICE 250,000 DWT in order to increase the energy efficiency of ship in particular the Energy Efficiency Operational Indicator (EEOI). So, these parameters need to consider including the fuel consumption level (HFO + DO), distance traveled, and cargo carried among these studied voyages. From then, the indication of k is equal 4 (k=4).

In Table 4, the experimental data of M/V NSU JUSTICE 250,000 DWT has been taken out the Noon-log Record for Voyage N^{o}16, N^{o}17, N^{o}18, N^{o}19, and N^{o}20. These parameters include the fuel consumption rate of engine corresponding to each certain voyage, types of fuel used both HFO (Heavy Fuel Oil) and DO (Diesel Oil), distance traveled, and amount of cargo carried. All of them were represented in Table 4 with these comparability sequences $x_i(k)$.

Item	Voyage	HFO (T)	DO (T)	Distance (NM)	Cargo (T)
1	N^{o}16	1485.773	15.3	7588	247400
2	N^{o}17	1663.1	13.3	7837	247500
3	N^{o}18	5434.67	27.6	24469	246200
4	N^{o}19	1680.941	17.1	7466	246876
5	N^{o}20	1479.477	13.2	7156	246800

Table 4: These comparability sequences $x_i(k)$. In where: Voyage N^{o}16= N^{o}16A+N^{o}16B, voyage N^{o}17=N^{o}17A+N^{o}17B, voyage N^{o}18=N^{o}18A+N^{o}18B, voyage N^{o}19=N^{o}19A+N^{o}19B, voyage N^{o}20=N^{o}20A+N^{o}20B.

These comparability sequences have been taken from the actual experimental data of M/V NSU JUSTICE 250, DWT researched. These parameters considered in this study concern about the energy efficiency operation index including the fuel consumption rates of engine (HFO+DO), the distance traveled (unit: NM = Nautical Mile), and a weight of cargo carried (unit: T = Ton). Especially, the optimization of these parameters hase been conducted in this research in aims with increasing the energy efficiency of ships. So, these comparability sequences $x_i(k)$ have been studied concerning about these parameters above and described in Table 4 corresponding to each certain voyage.

In Table 5, the reference sequences $x_0(k)$ were indicated that under the certain parameters then applied the Grey Relational Analysis (GRA) method to optimize the experimental data of M/V NSU JUSTICE 250,000 DWT. The reference sequences $x_0(k)$ are the operational parameters that M/V NSU JUSTICE 250,000 DWT wants to achieve these values. This means that the reference sequences $x_0(k)$ are desirable values and they are established completely based on the Grey Relational Analysis (GRA) method associating with the operational experience on M/V NSU JUSTICE 250,000 DWT.

Item	HFO (T)	DO (T)	Distance (NM)	Cargo (T)
$x_0(k)$	1479.477	13.2	24469	247500

Table 5: The reference sequence $x_0(k)$.

The reference sequence was designed to base on the actual experimental operation plus using the Grey Relational Analysis method. The reference sequence is corresponding to the desired sequence that the ship-owners and operators who want to gain these values. To optimize the energy efficiency operational indicator through the operational parameters then the fuel consumption rates of engine need to reduce along with ensuring the cargo carrying abilities of ships (distance traveled and amount of cargo carried). From the Grey Relational Analysis method, the fuel consumption level both HFO and DO (unit: Ton) is "the smaller the better" following the Equation (4) above. In contrast, the distance traveled (unit: Knot or NM – Nautical Mile) and cargo carried (unit: Ton) are "the larger the better" applying the Equation (3).

The difference sequences Δ_{oi} between $x_o(k)$ and $x_i(k)$ have been computed based on Equation 8 in section 3.2. This calculation of the difference sequences Δ_{oi} of these parameters concerning about the energy efficiency operational index corresponding at each voyage separated. These voyages have been studied total of five voyages with the certain name: N^o 16, N^{o}17, N^{o}18, N^{o}19, and N^{o}20 (n=5).

Δ_{oi}	Voyage	HFO (T)	DO (T)	Distance (NM)	Cargo (T)
Δ_{o1}	N^{o}16	6.296	2.1	16881	100
Δ_{o2}	N^{o}17	183.623	0.1	16632	0
Δ_{o3}	N^{o}18	3955.193	14.4	0	1300
Δ_{o4}	N^{o}19	201.464	3.9	17003	624
Δ_{o5}	N^{o}20	0	0	17313	700

Table 6: The difference sequences Δ_{oi} between $x_o(k)$ and $x_i(k)$.

The grey relational analysis coefficient $\gamma(k)$ has been calculated following the Equation 7 in section 3.2 above. These values have been recorded in Table 7 along with these values of grey relational analysis grade γ. The grey relational analysis coefficient of each voyage is a range of between 0 and 1 corresponding the each parameter needs to optimize in this study. In reality, there is a difference from these values collected and they will be compared and analyzed in section 5. On another side, the grey relational analysis grade will be indicated out at same table 7 responding to each grey relational analysis coefficient $\gamma(k)$. In where, there are four grey relational analysis coefficients $\gamma_1(k)$, $\gamma_2(k)$, $\gamma_3(k)$, $\gamma_4(k)$ corresponding to each parameter that needs to optimize. The analysis of the grey relational analysis coefficient and grey relational analysis grade will be carried out in section 5 of this article. From then, the optimization of the experimental data of M/V NSU JUSTICE 250,000 DWT will be represented.

$\gamma_i(k)$	Voyage N^{o}16	Voyage N^{o}17	Voyage N^{o}18	Voyage N^{o}19	Voyage N^{o}20	γ
$\gamma_1(k)$	0.9968	0.9150	0.3333	0.9075	1.0000	0.8305
$\gamma_2(k)$	0.7741	0.9863	0.3333	0.6486	1.0000	0.7485
$\gamma_3(k)$	0.3389	0.3423	1.0000	0.3374	0.3333	0.4704
$\gamma_4(k)$	0.8667	1.0000	0.3333	0.5102	0.4815	0.6383

Table 7: The Grey Relational Coefficient $\gamma_i(k)$ and grey relational grade γ.

5. Results and Discussion

The energy efficiency of ships plays a significant role in the shipping transportation industry. Especially, the energy efficiency measures have been established through the International Maritime Organization (IMO) that regulated in MARPOL 73/78, Annex VI about the Prevention of Air Pollution from Ships. The Energy Efficiency Operational Indicator (EEOI) is an operational measure, which is a target objective in this research in aims with reduction of the Energy Efficiency Operational Indicator associating with the sea environmental protection. These operational parameters have been concentrated on this research including the fuel consumption rates of engine, types of fuel used, distance traveled of certain vessel, amount of cargo carried responding to each certain voyage. Especially, the novel of this research has applied to the Grey Relational Analysis method to solve the issue in field of the energy efficiency of ships. Since these previous researches have just referred to apply and optimize the process parameters at some different fields. However, the use of Grey Relational Analysis (GRA) method for the shipping transportation industries still limits. So, this research has also indicated out the innovative trend in applying the Grey Relational Analysis method in field of optimizing the experimental data of vessels. In particular, this article has been represented throughout these results below then based on the Grey Relational Analysis (GRA) method.

The combination of calculating the Energy Efficiency Operational Indicator (EEOI) along with the Grey Relational Analysis coefficients and the Grey Relational Analysis Grade is initial background to conduct the optimize the energy efficiency operational index for a certain vessel, M/V NSU JUSTICE 250,000 DWT of VINIC shipping transportation company in Vietnam. Especially, this vessel has been operated by the author and Officers of VINIC shipping transportation company in Vietnam that some of them who work as Lecturers at Vietnam Maritime University, Haiphong, Vietnam. So, the optimization of experimental data for M/V NSU JUSTICE 250,000 DWT has been carried out in this research beside the Grey Relational Analysis (GRA) method applied.

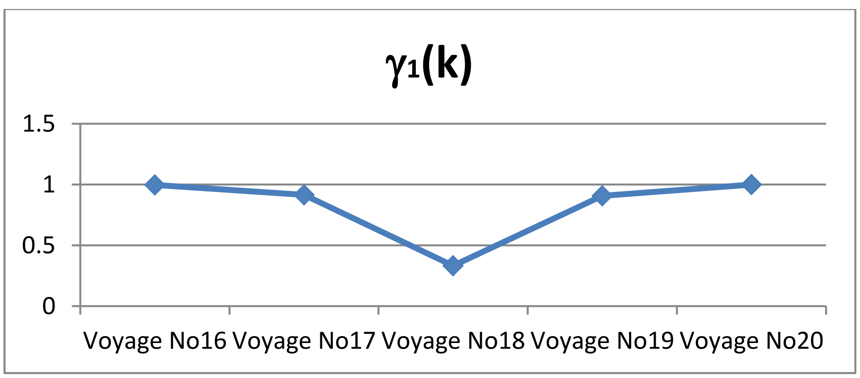

Figure 6: Grey relational coefficient $\gamma_1(k)$ for Heavy Fuel Oil (HFO).

In figure 6, the grey relational analysis coefficient $\gamma_1(k)$ is described for voyages including voyage N^{o}16, N^{o}17, N^{o}18, N^{o}19, and N^{o}20 about using the heavy fuel oil (HFO) on ship. In general, the maximum values of grey relational analysis coefficients are voyage N^{o}16 and N^{o}20 with 0.9968 and 1.0000. In contrast, the lowest grey relational analysis coefficient is voyage N^{o}18 with 0.3333. These left values for voyage N^{o}17 and N^{o}19 are in turns 0.9150 and 0.9075. In then, the grey relational analysis coefficient $\gamma_1(k)$ is represented for consuming the heavy fuel oil of engine on M/V NSU JUSTICE 250,000 DWT with the design value before then applied the Grey Relational

Analysis method. The grey relational analysis coefficient is as higher as better. So, the voyage N^{o}16, N^{o}17, N^{o}19, and N^{o}20 have used effectively about the heavy fuel oil on ship reflecting to voyage N^{o}18.

Similarly, the grey relational coefficient $\gamma_2(k)$ is also represented for all voyages in Figure 7. Throughout these results, the voyage N^{o}17 and N^{o}20 have the hight values corresponding to 0.9863 and 1.0000. In contrast, the similarity of grey relational analysis coefficient $\gamma_1(k)$ then the voyage N^{o}18 reaches the minimal value with 0.3333. These left voyages include voyage N^{o}16 and N^{o}19 in turn 0.774 and 0.6486.

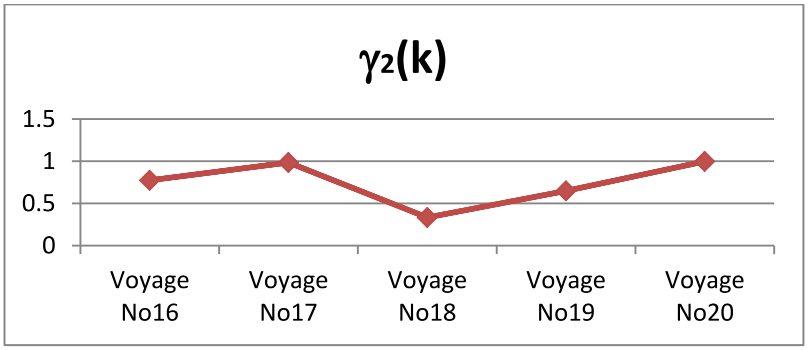

Figure 7: Grey relational coefficient γ_2(k) for Diesel Oil (DO).

The grey relational analysis coefficient $\gamma_3(k)$ is represented in Figure 8 below corresponding to each different voyage.

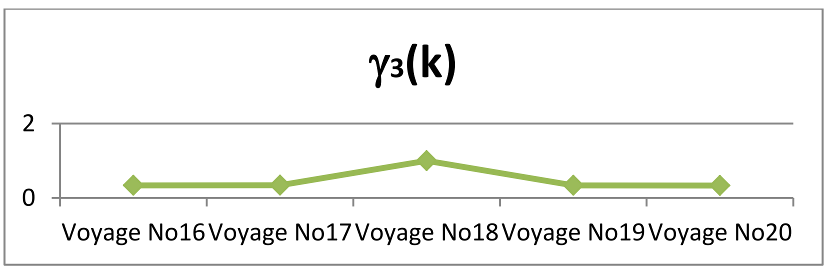

Figure 8: Grey relational coefficient γ_3(k) for distance traveled.

The grey relational analysis coefficient $\gamma_3(k)$ also indicates that the highest value of it is voyage N^{o}18 with 1.0000. These left voyages have these values similarly under 0.5000. In turns, the voyage N^{o}16, N^{o}17, N^{o}19, and N^{o}20 is 0.3389, 0.3423, 0.3374, and 0.3333.

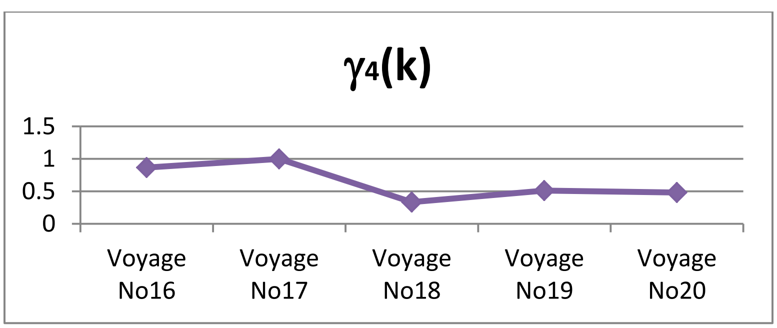

Figure 9: Grey relational coefficient $\gamma_4(k)$ for cargo carried.

The grey relational analysis coefficient $\gamma_4(k)$ for amount of cargo carried on M/V NSU JUSTICE 250,000 DWT also indicates in Figure 9. However, the highest value of grey relational analysis coefficient is voyage N^{o}17 (1.0000). These left voyages are in turn 0.8667 for voyage N^{o}16, 0.3333 for voyage N^{o}18, 0.5102 for voyage N^{o}19, and 0.4815 for voyage N^{o}20. Furthermore, the compound diagram between these gray relational analysis coefficients is represented in Figure 10 responding to each different voyage.

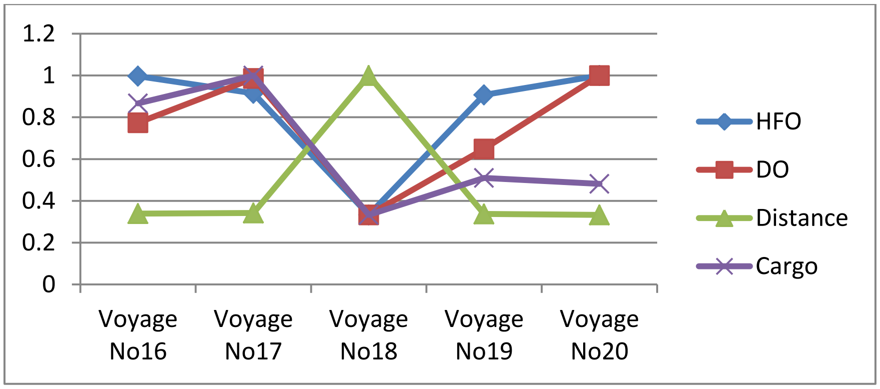

Figure 10: Grey relational analysis coefficients.

From the combination of the grey relational analysis coefficients each other also indicates that the distance traveled by ship has an important position in field of the energy efficiency of ships. Since it has been identified that voyage N^{o}18 achieved low value of the Energy Efficiency Operational Indicator (EEOI index = 1.13E-05) due to the grey coefficient analysis coefficient of this voyage gains the highest value (γ_3(k) =1.0000).

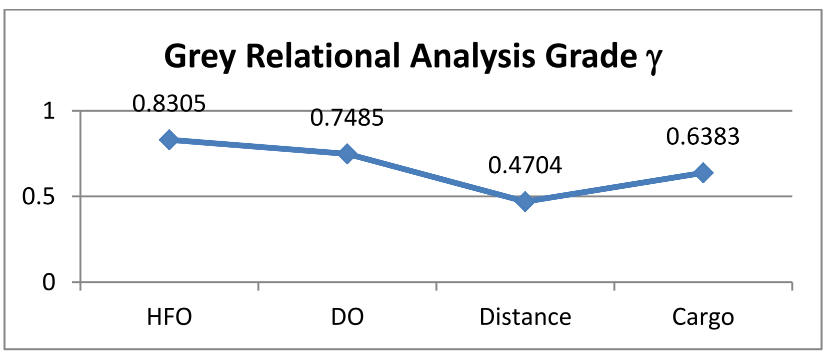

Figure 11: Grey relational analysis grades.

In figure 11, the grey relational analysis grade γ at each different element of the energy efficiency operation index is identified. The response of experimental data is separate at each voyage. The grey relational analysis grade of the heavy fuel oil consumption is the highest with 0.8305 after that in turn the diesel oil fuel oil consumption, amount of cargo carrier, and distance traveled with these values are 0.7485, 0.6383, 0.4704.

In a result, the optimization of energy efficiency of ships through these operational parameters needs to consider under these external factors impact. Moreover, to gain the optimal operation in field of operating and managing the energy used on board must consider about the fuel consumption rates including the heavy fuel oil and diesel oil with the distance traveled of ship.

6. Conclusion

This article has referred to the use of energy efficiency of engine on ship by applying the Grey Relational Analysis method in research. The use of effective energy on ship will be reduced the fuel consumption rate of engine nowadays as well as protection of sea environment following the International Convention for Prevention of Pollution from Ships (MARPOL 73/78). Besides that, these results also indicated that the optimization of energy efficiency operation index through these operational parameters is able to do completely when considering about the distance traveled of ships. Moreover, the distance traveled can be conducted by Masters of their ships. This task can be ensured that the energy efficiency of ships increases along with remaining the ship's safety in case of operation. In this research, the author has applied effectively the Grey Relational Analysis method in optimizing the experimental data of M/V NSU JUSTICE 250,000 DWT in field of the energy efficiency of ships. This is a new trend in the energy efficiency of ships especially using the energy economically on ships as well as restricting the exhaust gas emissions in the environment.

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