Uğur Demir

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EVALUATION OF OPERATIONAL FACTORS FOR THE ENERGY EFFICIENY OPTIMIZATION OF HIGH-SPEED RORO VESSELS BY TRIM OPTIMIZATION

UĞUR DEMİR

PİRİ REİS UNIVERSITY
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by

Uğur Demir

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APPROVED BY

Assoc. Prof. Dr. Ergün DEMİREL...

(Thesis Supervisor)

Asst. Prof. Dr. Kadir ÇİÇEK..

Asst. Prof. Dr. Dinçer BAYER..

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To the all Seafarers who passed away

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ABSTRACT

Fuel-Efficiency are the primary concern on management of Energy Efficiency in the maritime industry. The most substantial element of the running cost of vessels is fuel consumption, which also has a huge effect on Global Greenhouse Gases (GHG) emissions. International Maritime Organization (IMO) has formed the Energy Efficiency Operational Indicator (EEOI), which gives data concerning the energy of the ships in operation. The fuel consumption is the principal figures for the prognostication of EEOI and many operational standards are focusing on reducing fuel consumption such as speed adjustment, improvement of voyage plan, routing according to the weather forecast and arranging on time schedules. Trim optimization is one of the most used fuel-saving methods specified by IMO. Several of the studies in the literature are about Computational Fluid Dynamics (CFD) calculations and other theoretical methods. However, Literature needs more studies about the implementation of CFD results to real-life to evaluate if calculated results confirmed with the real-field data. During this research, real course data of high-speed RO-RO vessels evaluated and compared the outcomes of the Trim optimization software which is generated with the CFD method to define optimum trim conditions of these vessels corresponding with different displacements. Specially designed Trim Optimization software (Eco Assistant) based on CFD calculations developed by DNV GL was used by sister ships selected in this study. The vessels in which the dataset was obtained were built-in the identical shipyard in 2005 and had the equivalent technical details. They have completed the same Hull performance and displacement between certain ports in the same geographical area. The actual field data of the test vessels were evaluated with the methodology of ISO 19030 Standards to eliminate of operational factors affecting the energy efficiency such as hull performance, engine, propeller system ,displacement and speed, statistically analysed by means of tailed sample t-test and the fuel-saving results of Trim optimization software compared with the actual fuel consumptions outcomes. As a result, it has been observed that trim optimization software based on CFD calculations provides fuel saving among only one of the vessels tested.

ÖZET

Yakıt Verimliliği, denizcilik endüstrisindeki Enerji Verimliliği Yönetiminin temel sorunudur. Gemi işletme maliyetinin en önemli kısmı, Sera Gazı (GHG) emisyonları üzerinde de büyük etkisi olan yakıt tüketimidir. Uluslararası Denizcilik Örgütü (IMO), faaliyette olan gemilerin etkinliği hakkında bilgi sağlayan Enerji Verimliliği Operasyonel Göstergesini (EEOI) geliştirmiştir. Yakıt tüketimi, EEOI hesaplamasında ana kriterdir ve, hız ayarlaması, sefer planının iyileştirilmesi, hava durumu rotaları ve sefer sürelerinde düzenleme gibi birçok operasyonel standard, yakıt tüketimini azaltmaya odaklanmaktadır. Trim optimizasyonu, IMO tarafından belirtilen en çok kullanılan yakıt tasarrufu sağlayan yöntemlerinden biridir. Literatürdeki Trim optimizasyon çalışmaların bir kısmı Hesaplamalı Akışkanlar Dinamiği (CFD) hesaplamaları ve diğer teorik yöntemler ile ilgilidir. Bununla birlikte, Literatürde, CFD yöntemi ile hesaplanan sonuçların, gerçek alan verileriyle karşılaştırmasını sağlamak ve değerlendirmek için CFD sonuçlarının gerçek hayata uygulanması hakkında daha fazla çalışmaya ihtiyaç vardır. Bu çalışmada, yüksek hızlı RO-RO gemilerinin gerçek saha verileri ile farklı deplasman ve hızlara karşılık gelen optimum trim koşullarını tanımlamak için CFD yöntemiyle üretilen Trim optimizasyon yazılımının sonuçları karşılaştırılmıştır. DNV GL tarafından geliştirilen CFD hesaplamaları temeline dayanan ve özel olarak dizayn edilmiş Trim Optimizasyon yazılımı (Eco Assistant) bu çalışmada seçilen sister gemiler tarafından kullanılmıştır. Verilerin elde edildiği gemiler, 2005 yılında aynı tersanede inşa edilmişler ve aynı teknik detaylara sahiplerdir. Aynı coğrafi bölgedeki belirli limanlar arasında aynı karina performansı ve deplasman ile seferlerini tamamlamışlardır. Test gemilerinin gerçek alan verileri, ISO 19030 Standartları metodolojisi ile değerlendirilmiş olup karina performansı, makine ve pervane sistemi ve deplasman gibi enerji verimliliğini etkileyen operasyonel faktörler elemine edilmiş ve tailed sample t-test ile istatistiksel olarak analiz edilmiştir ve Trim optimizasyonu yazılımının vermiş olduğu yakıt tasarrufu sonuçları ile karşılaştırılmıştır. Sonuç olarak CFD hesaplamalarına dayanan trim optimizasyon yazılımının test edilen gemiler arasında sadece bir tanesinde yakıt tasarrufu sağladığı gözlemlenmiştir

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LIST OF SYMBOLS/ABBREAVATIONS

°C: Celcius degree
A_hull :Area of the wetted surface
C: Resistance coefficient
CFD: Computational Fluid Dynamic
CFj: The fuel mass to CO2 mass conversation factor for fuel
CH4:Methane
CO2:Carbon Dioxide
DDI: Dry-docking Interval
DDn
DDn+1: Next Dry-Docking
DOE: Design of Experiment
E: Post-Period
EEDI: Energy Efficiency Design Index
EEOI: Energy Efficiency Operational Indicator
F:Speed-Power Curve
FCi j :The mass of consumed fuel at voyage
GHG: Green House Gases
H:Hull and Propeller Performance
HFCs:Hyrdrofluorcarbons
HFO: Heavy Fuel Oil
IMO: Internatiopnal Maritime Organization
ISO:International Organization for Standardization
i: mass of consumed fuel at voyage
j:Fuel type
kg:Kilogram
kJ:Kilogram Joule
Kn: Knot
LCV:Lower Calorific Value
LFO:Ligth Fuel Oil
m:Metre
MARPOL: International Convention for the Prevention of Pollution from Ships
mcargo:cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships
ME: Main Engine
MPEC: The Maritime Environment Protection Committee
MSC: Military Sealift Command
N2O: Nitrous oxide
Nm:Nautical Miles
PFCs: Perfluorocarbons
PI: Performance Indicator
pp: Propulsion
R:Resistance
R_i: Propeller Pitch
RO-RO: Roll on / Roll Off Vessels

s:Second
SEEMP: Ship Energy Efficiency Management Plan
SF6: Sulphurhexafluoride
SFOC: Specific Fuel Oil Consumption
t:Tonnes
TEU: Twenty Equvalent Unit
UNFCCC: United Nations Framework Convention on Climate Change
V: Speed
VoF: Volume of Fluid
ηR: Rotative Efficiency
ρ: Density
η _B: Efficiency Factor of the Propulsion

1 INTRODUCTION

Fuel combustions is responsible from 2, 5 % of global Greenhouse gases emission and it is estimated that maritime transport emits 1 billion ton of carbon dioxide annually [1]. Future projection indicates that through 2050 depending on business increase and improvements on energy, transportation emissions may rise to 250 %

In 2002 the Kyoto Protocol to the UNFCCC has been signed [2]. Article 2(2) is stated that "The Contractors involved in Annex I shall attempt control or decrease of emissions of greenhouse gases not regulated by the Montreal Protocol from aeronautics and maritime bunker fuels, running through the International Civil Aviation Organization and the International Maritime Organization, sequentially.

The important Green House Gases are classified in Annex A

- "Carbon dioxide (CO_2)"
- "Methane (CH_4)"
- "Nitrous oxide (N_2O)"
- "Hydrofluorocarbons (HFCs)"
- "Perfluorocarbons (PFCs)"
- "Sulphur hexafluoride (SF_6)"

Shipping emits a huge amount of CO_2 which is a well-known GHG [3]Portions of CO_2 may stay in the air for a very long period and create significant climate heating. Shipping also emits other pollutants such as cooling gases and SO_2 and NOX. These pollutants have complex but warming and cooling effects, although their life is shorter.

In a complete combustion the products are carbon dioxide, water and Sulphur dioxide only. If the combustion is incomplete, mainly carbon monoxide and partly oxidized and unburned hydrocarbon compounds "hydrocarbon emissions" are produced. If there is a lack of air, CO is generated first; Hydrocarbons (irritations of eyes and mucous membranes), Nitrogen oxides (NOX), Sulphur oxides (SOX) and particles (detrimental to health and carcinogenic) follow.

Emissions can be reduced by engine modifications and there are numerous worldwide and local laws for emission control. [4]

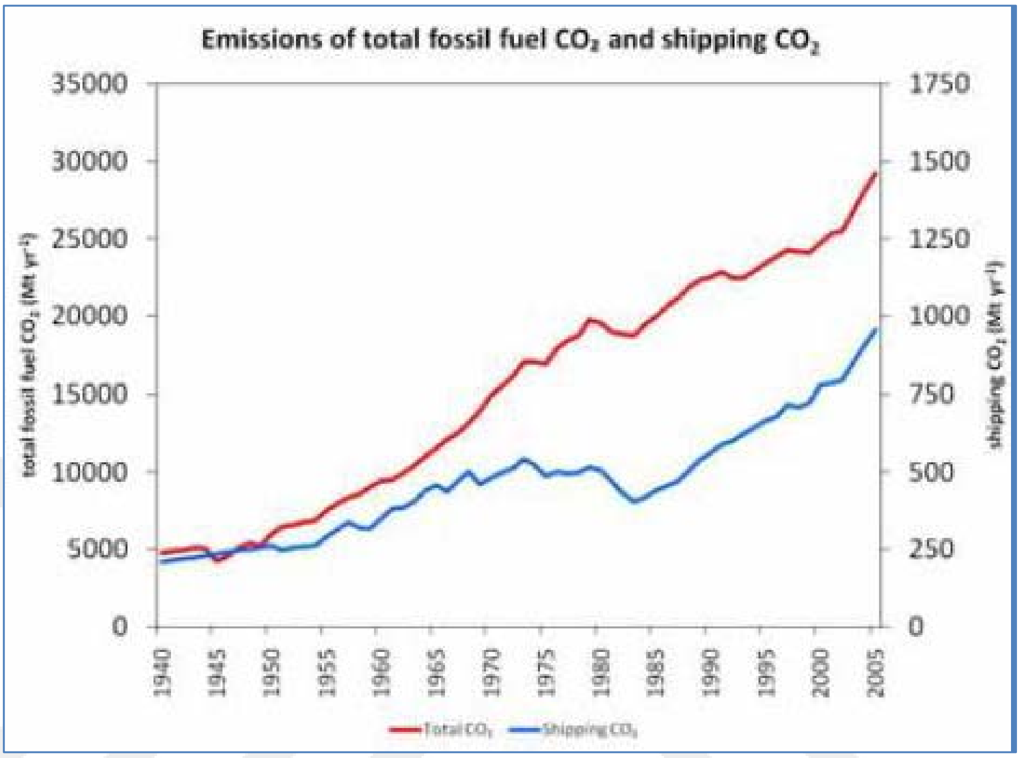

Figure 1 Historical development of CO2 emissions from maritime transport [3]

1.1 IMO Studies on "Energy Efficiency of the Ship"

To decrease emission of the Greenhouse gases from transport business, "The Maritime Environment Protection Committee (MPEC)" of "International Maritime organization" brought mandatory measures in 2011 [5]. Following to this, as new chapter the Energy Efficiency regulations has been added to "International Convention for the Prevention of Pollution from Ships" (MARPOL). That chapters adopted the "Energy Efficiency Operational Indicator (EEOI)" and Ship Energy Efficiency Management Plan (SEEMP) as compulsory for all vessels.

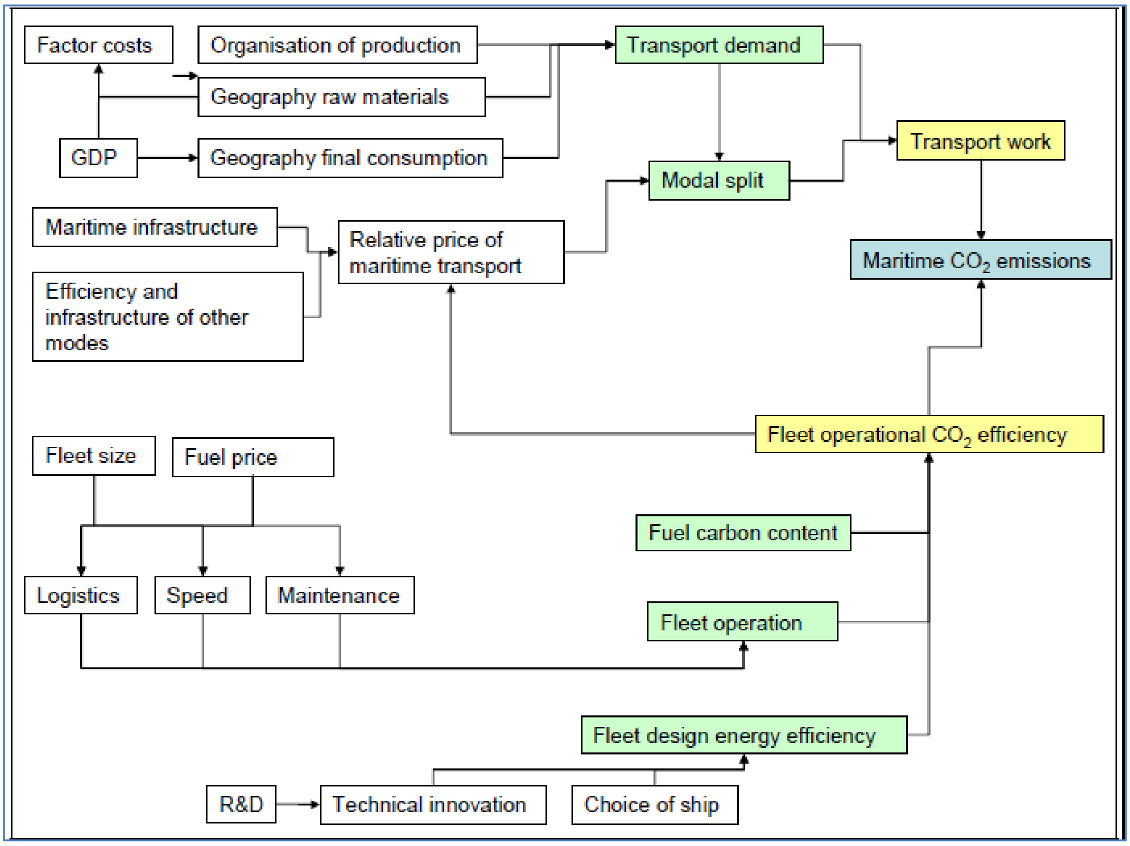

Figure 2 Stylized representation of factors determining maritime emissions [3]

1.2 Ship Energy Efficiency

The IMO, in July 2011 [5], utilized actions to decrease vessels' emissions of greenhouse gases (GHG) i.e the "Energy Efficiency Operational Indicator (EEOI") and the "Ship Energy Efficiency Management Plan (SEEMP)". The EEDI has been declared obligatory for new vessels and the SEEMP for both new and existing vessels, by revisions to MARPOL Annex VI [5]. According to the IMO, the adoption of these compulsory standards for new ships (EEDI) and for all vessels in running (SEEMP) from 2013 onwards will drive to meaningful emission reductions i.e. by 2020, up to 180 million tons of CO2 yearly; a figure that, by 2030, will increase to 390 million tons of CO2 yearly. The reductions will be between 9 and 16% in 2020 and between 17 and 25% by 2030 matched with prevailing method [6] the emission decrease actions will also result in notable fuel cost savings to the shipping trade, although these gains will expect higher investments in more efficient vessels and

More advanced technologies than today. The Marine Environment Protection Committee, at its session in July 2017, was suggested that approximately 2,500 new vessels had been accredited as complying with energy efficiency measures. Between others, the Committee affirmed guidelines for administration affirmation the vessel fuel oil consumption data for vessels of 5,000 gross tonnage and over, beginning from 2019, and guidelines. for the development and management of the IMO ship fuel oil consumption database [7] [8] Those guidelines perform it compulsory for vessels of 5,000 gross tonnage and over to obtain consumption data for any type of fuel oil they burn, as well as extra detailed data, including agents for the transportation industry. The aggregated data will be summarized to the flag State after the end of every calendar year, and finally transported to the IMO database.

1.3 The Ship Energy Efficiency Management Plan

"The Ship Energy Efficiency Management Plan (SEEMP)" [9] ensure an operational set of standards that gives a general strategy to develop the energy efficiency of a vessel in terms of cost savings and efficiency. It supports the most suitable fuel-efficient applications on vessel operation. It improves the ship operators or fleet managers to recognize new technologies and methods when attempting to optimize the performance of a vessel at every section of the SEEM.

1.4 Energy Efficiency Operational Indicator

"Energy Efficiency Operational Indicator" is an indication to observe fleet efficiency and performance by a specific time on the operating of the vessels [10] The EEOI assists ship managers/ship partners to measure the fuel efficiency of a ship and to show the effect of any differences in the operation. E.g., trim optimization, improved voyage planning, and more frequent propeller cleaning, or the accomplishing of some technological initiatives as waste heat recovery plants, re-fitting of bulbous bow, or a new model of propeller design produces fuel savings.

The rate of the EEOI differs considerably over the business circle. It depends on the quantity of cargo, source and destination, weather, etc. So seldom it can be met very quickly, but in other times or locations, it cannot be given at all.

The EEOI cannot be compared across ship types.

Certainly, it can be described as the ratio in mass of CO2 (M) emitted per unit of transport work. The primary formula for EEOI for a voyage as following; [11]

$$EEOI\ = \frac{\sum_j FCj\ x\ C_{fj}}{m_{cargo\ X\ D}} \quad (1)$$

Where: [11]

• “j is the fuel type”; [11]

• I is the voyage number;” [11]

• FCi “j is the mass of consumed fuel at voyage”; [11]

• CFj “is the fuel mass to CO2 mass conversion factor for fuel “; [11]

• “mcargo is cargo carried (tones) or work done (number of TEU or passengers) or gross tonnes for passenger ships”; and [11]

• “D is the distance in nautical miles corresponding to the cargo carried or work done” [11]

“A simple model, including one ballast voyage, for instance purposes only, is given below”

Table 1 A single case including ballast Voyage of an example vessel

Fuel consumption (FC) at sea and in port in tonnes				Voyage or time period data	
Fuel type (HFO	Fuel type (LFO	Fuel type ( )		Cargo (m) (tonnes or	units) Distance (D)
20	5			25000	300
20	5			0	300
50	10			25000	750
10	3			15000	150

$$EEOI = \frac{100 \times 3.114 + 23 \times 3.151}{(25000\ \times 300) + (0\ \times 300) + (25000\ \times 750\ ) + (15000\ \times 150)}$$

$$= 13.47\ \times\ 10^{-\,6}$$

Unit: tonnes CO2/ (tons . • nautical miles)

1.5 Operational Factors of The Ship Energy Efficiency Optimization.

1.5.1 Vessel Resistance

The total resistance is a combination of wave, wind and frictional resistance stated as below; [12]

$$R_{total} = R_{frictional} + R_{wave} + R_{wind} \quad (2)$$

Frictional resistance is created by the ship 's hull, which is under the waterline. Resistance of the sea wave is the combine resistance happened by waves induced by the environment, and the vessel's individual wave occurred while advancing and wind resistance is the resistance produced due to wind influence the vessel structures above the waterline

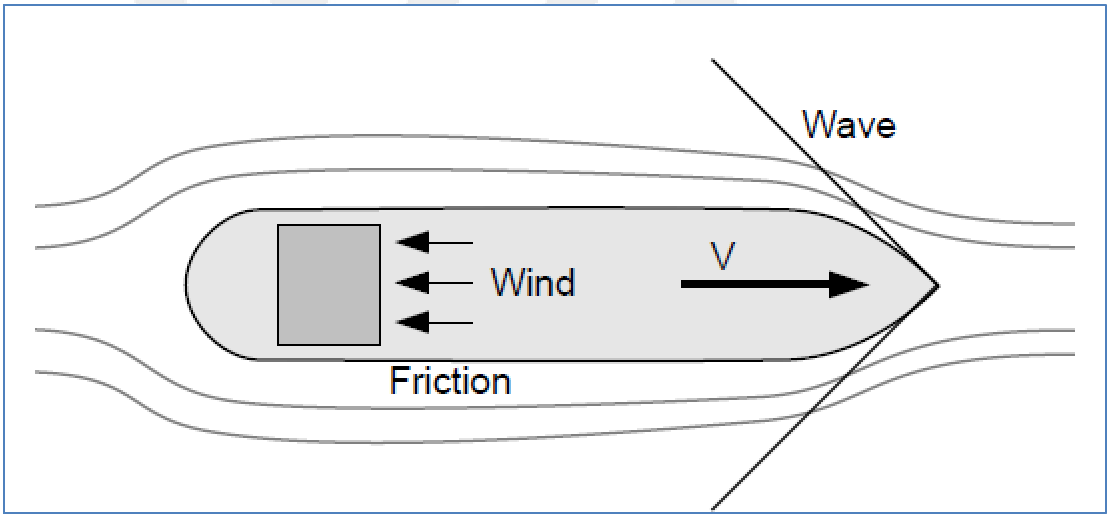

Figure 3 Wave resistance [4]

1.5.1.1.1 Frictional Resistance

45-90% of the total resistance is consist of the frictional resistance [13] The frictional resistance is related to speed and increases as a rate of square of the vessel 's speed. It depends on the section of the hull is below the waterline as well as the form of the hull. For this reason, displacement, trim of a vessel also be the influence of the resistance caused by the friction as well as the form of the hull of a vessel is asymmetrical

Additionally, the vetted surface is also compelled to microorganisms which produced the resistance considerably while developing by time.

Consequently, the frictional resistance is consisting of hull resistance, the fouling resistance, and the resistance caused by different trim and displacement resistance correspondingly.

Hull Resistance

Based on Bernoulli's law says that the water's dynamic pressure by density ρ provides a resistance to the hull form

$$R_{hull} = \frac{1}{2} C_{\rho} V^2 A_{hull} \tag{3}$$

Where V is the speed, A_{hull} is the area of the wetted surface, and C is the resistance coefficient, which is dimensionless. Thus, the fact that the frictional resistance extremely influences the vessel's speed.

1.5.1.1.2 Fouling resistance

Fouling is the name commonly used to define the settlement and growth of marine plants and animals on immersed constructions. Fouling enhances the frictional resistance of a vessel and creates speed loss and a rise in fuel consumption. Sailing routes have a tremendous influence on fouling considering some fields have more important fouling results than others, both. seasonally and regarding locally. [12]

Table 2 Statistical results of test vessel, Fuel Consumption Changes [14]

	Mean	N	Std. Deviation	Std. Error Mean
Last year before dry-dock	2,3207	36	0,09590	0,01598
First year after dry-dock	2,1969	36	0,07445	0,01241

	N	Correlation	Sig.
Last year & First year	36	-0,098	0,569

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Last year & First year	0,12376	0,12705	0,02117	0,08077	0,16675	5,845	35	0,000

Table 2 show a statistical fuel consumption of 29004 Gross Tonnage Ro-Ro vessel with a twin propeller, last year dry dock and first year after dry dock., it is easily seen that that average fuel consumption reduced due to clean hull when comparing dirty hull condition before dry dock as %5 [14]

Table 3 Statistical results of Vessel 1, Speed Changes [14]

	Mean	N	Std. Deviation	Std. Error Mean
Last year before dry-dock	19,3800	36	0,51440	0,08573
First year after dry-dock	19,8533	36	0,51122	0,08520

	N	Correlation	Sig.
Lsst year & first year	36	0,173	0,312

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Lsst year & first year	-0,47333	0,65943	0,10991	-0,69645	-0,25021	-4,307	35	0,000

The table 3 shows the change of average speed of the subject RO RO vessel as increasing % 2,4 after dry dock with a clean hull condition according to the average speed made during the last year before dry dock. [14]

1.5.1.1.3 Effect of displacement and trim variations

The amount of water is displaced by a vessel is also described as displacement, and this mass of water is equal to the total weight of the ship, Draught difference between aft and forward of a vessel is also named as trim. See in figure 6.

Thus, Trim and displacement are among the main operational conditions which could be controlled by means of transferring, ballasting and de-ballasting the vessel's ballast water.

Several studies have revealed that the delivered power performance alters significantly with different displacement and trim conditions. [13] [15] [16] [17] [18]

Furthermore, the energy loss is also linked to the shape of the structure, the flat bottom, and the displacement. In many laying contours, the form of the hull under the waterline varies frictional resistance

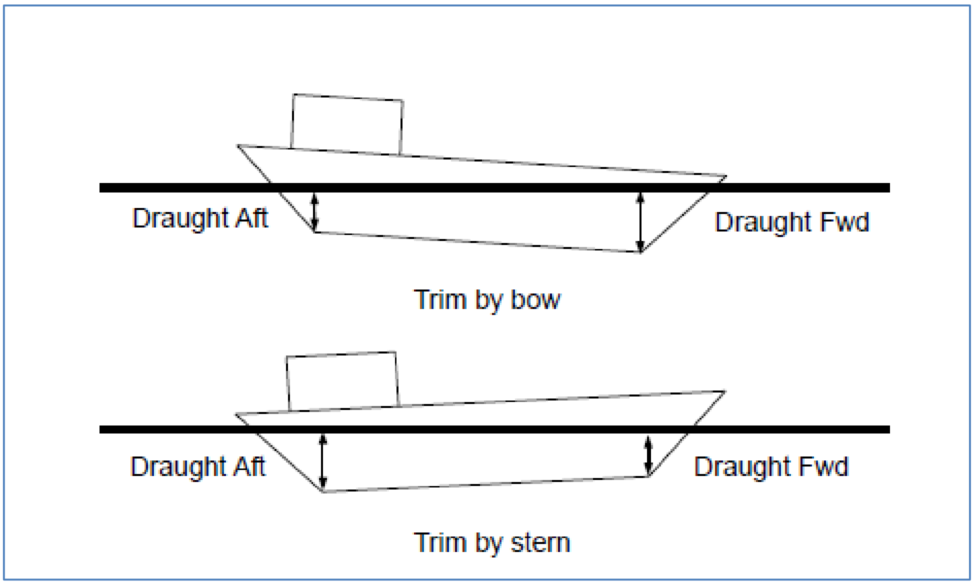

Figure 4 Trim of the Vessel, by bow & by stern [4]

Figure 4 presents the impacts of various displacement arrangements at fuel consumption when the vessel is even keel position. The increase of ship's draft produces a significant Fuel consumption

Figure 5 presents how trim settings influence combustible while displacement is kept in constant by transferring ballast water.

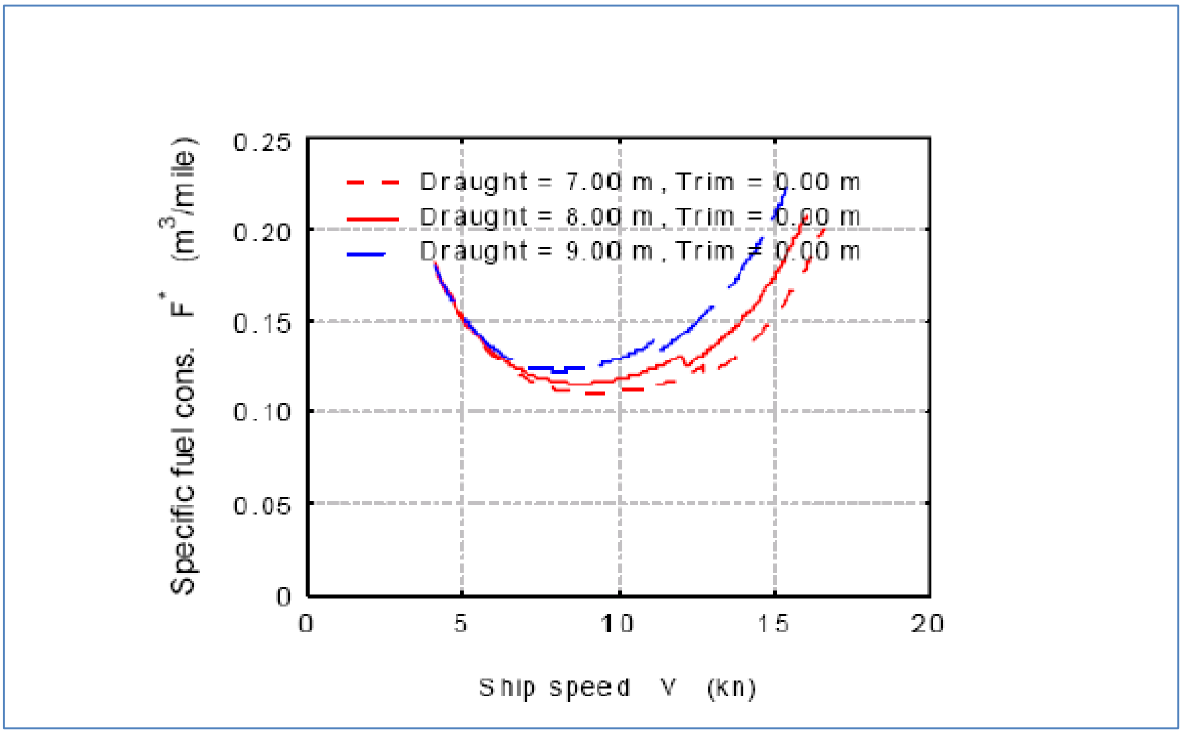

Figure 5 Relationship among Speed and Specific Fuel Consumption of vessel [16]

Figure 5 The link among F (Specific Fuel Consumption) and V(speed) for various draft, and even keel. Consumption of fuel increases as the draft increases [16].

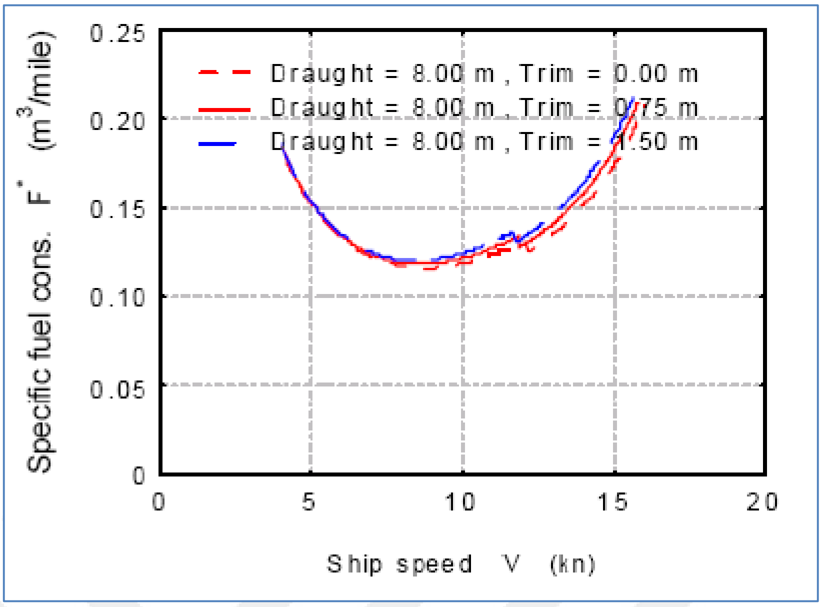

Figure 6 Relationship among the Speed and Specific Fuel Consumption of vessel [16]

Figure 6: The correlation between V, (speed of vessel) and, F (specific fuel consumption of vessel) for various arrangements of trim, by draught at 8m. The consumption of fuel varies smoothly with different trim configuration [16]

An inadequate increment of fuel consumption per mile with an expanding trim

1.5.1.1.4 Other Resistance

In this thesis, it is not mentioned that different conditions could alter the frictional resistance, such as degeneration of the coating or corrosion of the hull. Both hit the frictional resistance instantly. Morover bad weather conditions and inadequate cargo loading can also be considered among the operational factors that have an influence on frictional resistance. Furthermore, shoal areas have an influence on the resistance as the displaced seawater under the vessel will have more prominent difficulty in running to the aft. [13]

1.5.1.2 Wind Resistance

The wind has a portion up to 2-10 % of the total resistance affecting the structure of the vessel above water with wind surface of the vessel and air draught correspondingly [13]. One of the external operation factors of energy efficiency is the uncontrollable wind resistance differs by direction and force of the wind. The wind resistance depends on the vessel's speed and increase as the square of the speed of the vessel and Resistance is substantially equivalent to the square of the vessel's speed, and equivalent to windage surface of a vessel remains above of the waterline. Obtaining a proper method for foretelling wind resistance can be a challenging task [19] corresponding the type of vessel in any dimensions and shapes e.g., cargo ships, tankers, cruise liners or Ro-Ro vessels

1.5.1.2.1 Resistance of Steering

to be able to steer a vessel on a specific course while wind blows near abeam of the vessel, a specific rudder angle must be used to meet winds effect at any given time [17]. That will generate an additional resistance to the combine resistance to vessel. The heading input to the autopilot to keep the vessel in the desired course continuously would cause the vessel advancing while yawing when sailing in waves. it will produce divergent forces of which the element R_{ST}, this end as a combined resistance in the longitudinal path [17] (see figure 7).

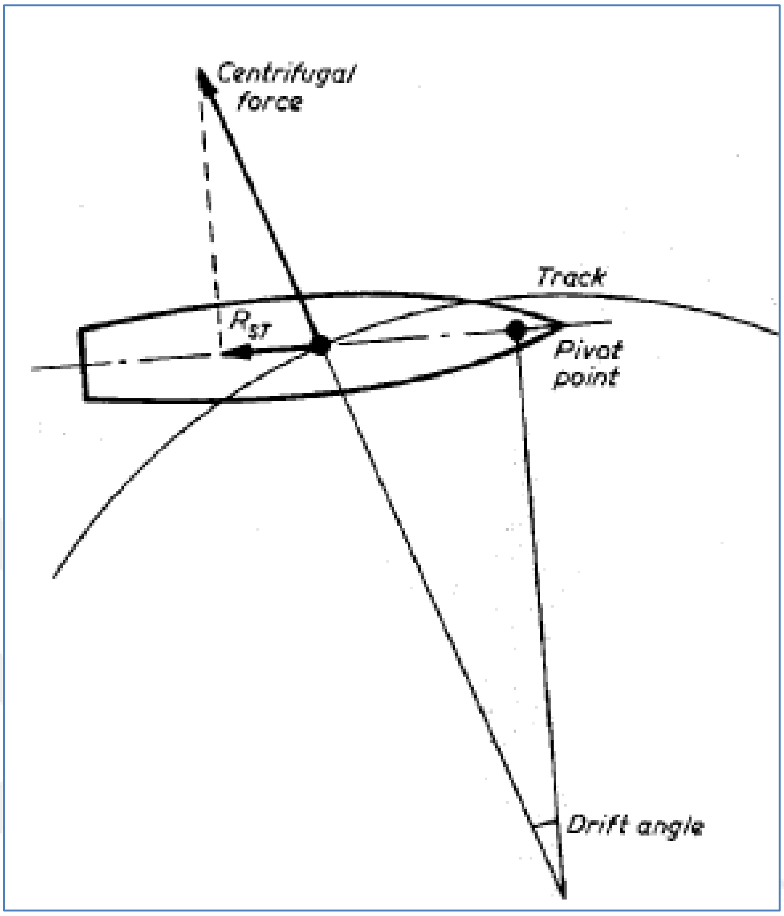

Figure 7 The Resistance of Steering [20].

Figure 7: The centrifugal force creates the resistance of steering, while the vessels steamed with rolling motions caused by the waves and changing course via autopilot.

1.5.1.3 Wave Resistance

The surface of the water is regarded to be the result of the various simplistic harmonious waves, with its own frequency, direction and length of the wave prevail [20]. Generally, the sea waves consist of two types of waves

Sea waves generated by wind are of the induced type. The force of the wind settles the sea waves through airflow pressure on the lee side of the crests and throughout its friction on the wave's surface. The growth of waves generated by wind starts with the generation of ripples, which are thin waves. As the thin waves rise, they transform into gravitational waves, which continuously increase in length and height. In their first degree of expansion, the waves move in lateral boundaries, which are divided into individual crests. The surface of the water mixed up by the wind gets in a pretty mixed shape, which continuously varies over time. Sea waves induced by wind can always be seen on the surface of the sea, and their dimensions are most varied.

Swell waves are produced outside of the vicinity, frequently produced by winds several nautical miles away. They are natural, and the crests are extended rounded. Moreover, waves move with a lower frequency and have a significant height of wave.

Regarding above information it clearly understood that waves are also uncontrollable operational factor of energy efficiency.

Moving of vessel through water and hitting surface of the sea also creates the resistance of wave. [14] [20].

Figure 8 shows combination of the mean resistance of wave and resistance created by vessel moving through the calm sea.

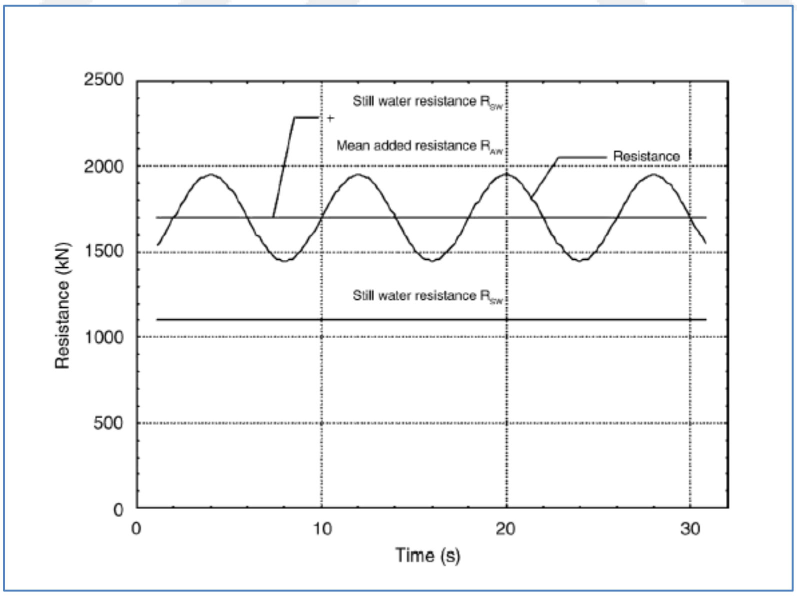

Figure 8 The resistance combination in real and resistance of mean water created by constant waves. [20]

In either circumstances, vessel is delivering its energy to seawater and caused an additional resistance has to be succeeded to keep the vessel's speed [17]. Most substantial part of the additional resistance of the wave belongs to the ship motion vertically. [17] [21] [22] Where the 5-45% of the total resistance come from. [13]. The resistance of waves is basically equivalent to the square of the speed of the vessel.

Speed limitation could be required as the additional increment of the vessel's thrust of propeller power will not happen at a higher speed as the largest of the power will be converted into the vessel's energy.

Figure 9 describes How the vessel's speed reduces considerably in head waves. It is complicated and hard to foretell the resistance of the wave of the vessel. Various techniques include any forecast of resistance of waves. [21] , but their prediction results usually have less accuracy [21]

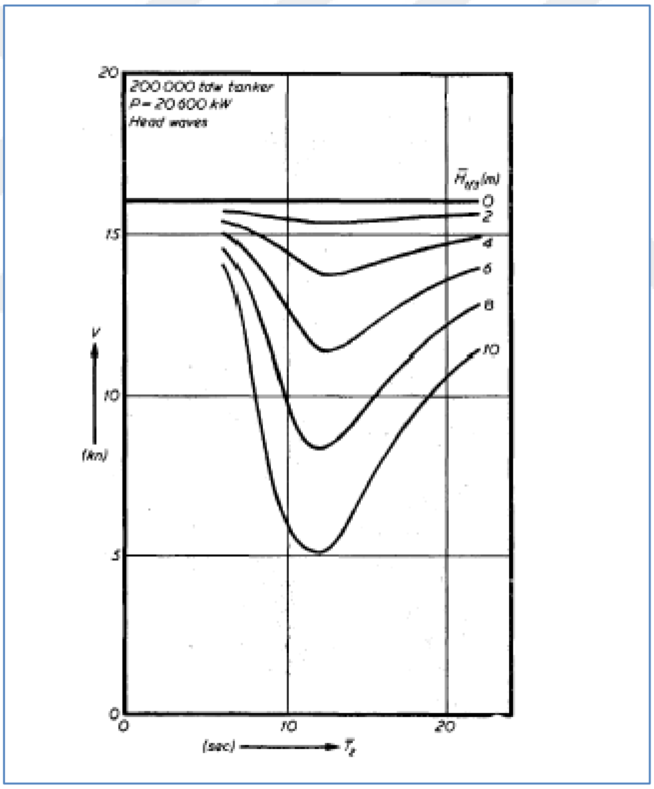

Figure 9 The correlation among time and speed of a 20.0000 DW tanker when sailing in bow waves [21]

Figure 9: The correlation among time and speed of a 20.0000 DW tanker while steaming towards waves from bow. Curved lines define speed decrease while navigating within different waves have a height of 2-meter, 4 meter, 6 meter, 8 meter, and 10 meter respectively.

1.5.1.4 Total Resistance

Table 4 shows the components of each resistance element to the total resistance.

Table 4 shows the components of each resistance element to the total resistance

Resistance	% of Total Resistance
Friction	45-90
Wave	5-45
Wind	2-10

Operational and external conditions influence the total resistance.

Among the operational factors, such as displacement and trim and speed, are controllable factors that influence the total resistance of a vessel. The environmental factors like waves and winds are uncontrollable components of the operational factor directly affecting the total resistance of the vessel.

1.5.2 System of Propulsion

The propeller creates the thrust force, and this force must be in balance with the whole resistance to influence the vessel. This force produced by propellers with converting the energy created via burned fuel into thrust and overcome as the resistance as vessel moving at a certain speed.

Following shows the process on the power is created via system of propulsion. The principal source of power of the propeller is mainly the diesel engine that the fuel is converted into brake power, P_B .

The link between the specific fuel consumption (SFOC) and Fuel Consumption, and the brake power is

$$Fuel\ Consumption = \int P_B \,.SCOF.(\,P_B)dt \tag{4}$$

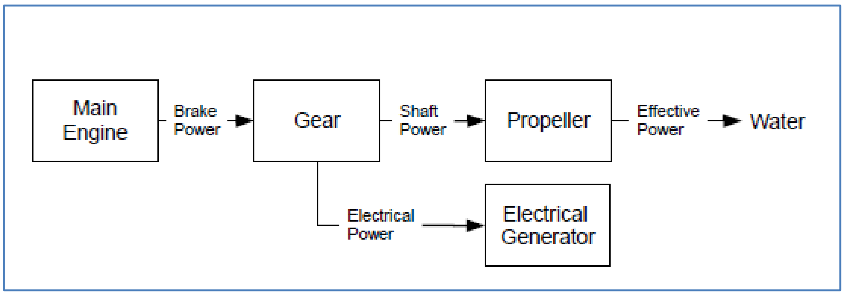

Figure 10 Flow chart of System of Propulsion

The break power produced from fuel is delivered to shaft and generated. The propellers convert the shaft power into thrust and deliver to the water is that also defined as effective power

Figure 11 represents link between load of engine and specific fuel consumption that is described as P_B= P_{Bmax} where P_{Bmax} is upmost power created by the engine.

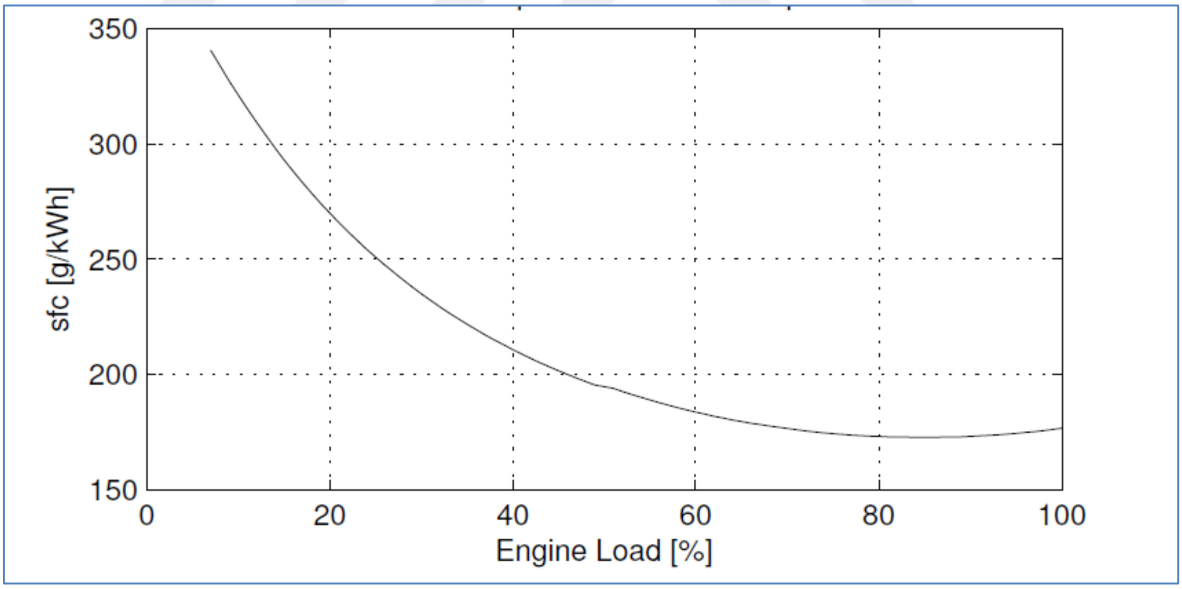

Figure 11 link between load of engine and specific fuel consumption

Figure 11 illustrate that specific fuel consumption has direct relationship with the engine load, which is defined as $P_B = P_{Bmax}$ and where P_{Bmax} is the maximum power delivered by the engine at a revolution per minutes.

The brake power is the power delivered to shaft system P_B is also transmitted to generator via of the gear reduction:

$$P_{B\,.} = \eta_B(P_{S+}\ P_{el}) \tag{5}$$

The shaft power, is P_s , P_{el} is the power delivered to the generator and η_B is the gear's efficiency factor in which is admitted being fixed. Eventually, the shaft power is transmitted to the propellers,

$$P_B = \eta_B P_D \tag{6}$$

where P_D is power transferred to Propellers and η_S is the shaft's efficiency factor that is assumed. to be fixed. Thrust produced by power of the propeller transmitted to the seawater

$$P_E = \eta_p(pp, V, n)\, P_D(\mathrm{V}) \tag{7}$$

where η_p propulsion efficiency factor, which is related to propellers'picth, pp,

V, is the speed

the rpm of the shaft, n. T

PE is vessel's effective power. i.e. the power requires to steer the vessel in the water at a certain speed (V)

Usually, the shaft of the vessel rotates with a constant rpm velocity. Vessel speed can be controlled by the propeller pitch, which is a component of operational conditions. The relationship between the ,P_E, R_i, pp, and V , is determined with below equation [13]

$$P_E(pp, V) = V \sum_i R_i\,(V) \tag{8}$$

is showing that various of the resistances additionally change on the various speed.

equation restated by joining equalization two, equalization three and equalization four asserted earlier

$$P_{S}= \frac{V \sum_i R_{i\,(V)}}{\eta_p . \eta_{s\,(pp,V)}} \qquad (9)$$

Consequently, the shaft power succeeds the total resistance.

1.6 Most Preferred Methods for Fuel-Efficient Operation of Ships

IMO has highlighted remarkable options in regard to “Fuel-efficient” operations are below [9]

1.6.1 Improved voyage planning

A thoroughly planned and performing the voyage plan involving the optimized routes that can help to decrease consumption of bunker and improve “Efficiency” of vessel.

Various software tools in the market provide voyage optimization [9]

1.6.2 Weather routing

It can be obtained a huge potential saving for fuel on special courses. This route can be can provide remarkable fuel savings.

However, at the same time, weather routing could also raise the consumption of fuel for a specific voyage. [9] The distance of two points of the voyage should be taken into account when applying “Weather Routing”.

1.6.3 Optimization of Vessel’s Speed

Optimization of speed may create meaningful savings. Nevertheless, the best speed indicates the value of speed in which the consumption of fuel according to the tonne mile is at the minimum speed value on that specific voyage.

this does not indicate minimum speed; sailing at smaller than best speed is going to spend more extra fuel preferably than more limited. [9]

1.6.4 Optimization of Vessel's Shaft Power

Continuously setting speed over engine power may produce more fuel consumption than an operation at fixed revolution per minute (RPM).

Automation engine management systems can command the engine speed rather than human interference may be advantageous. [9]

1.6.5 Ballast Optimization

Optimization of ballast of a vessel can shortly be defined as ballasting for best trim and displacements and steaming positions. The "*Ballast Water Management Plan*" and *Loading and stability Manual* "of vessel usually give required information on arranging best ballasting of a vessel [9]

1.6.6 New Designs of Propellers

Various retrofit design works or newly designed and produced propellers may provide notable fuel savings — for instance, ducts, fins to improve the "*Energy Efficiency*" of a vessel [9]

1.6.7 Effective using Method of rudder and Course control arrangements

Short cuts on sailed distance during a voyage of vessels by means of avoiding deviation from the intended course and avoid add on consuming fuel caused by correction of heading value may increase "*The Energy Effi*ciency" of a vessel. Retrofitted rudder blades also provide remarkable improvements in efficiency. [9]

1.6.8 Hull maintenance

The new coating technologies and systems reduce the hull 's friction resistance on a vessel which remains underwater. It is essential that provide a systematic inspection and maintenance of the hull of a vessel for better fuel efficiency. [9]

1.6.9 Propulsion system

It is a methodical way avoiding heat and construction loss throughout regular keeping and optimization. New model engines which are typically controlled as electronically may improve the gains from the efficiency. In this regard vessels crew should be trained to reach maximum gains from the regular maintenance of engines [9]

1.6.10 Waste heat recovery

In recent years it becomes essential to recover the energy from engine propulsion via shaft motors or thermal heats emitted exhaust gases using retrofit some systems into existing vessels. Thus, generate electricity.

Most of the shipping owner or shipyard should be invigorated to apply this kind of new technologies [9]

1.6.11 Improvement applied fleet management

Well-structured fleet Management provides a better use of fleet capacity and use of “best practice” this can be likely to withdraw or decrease continued ballast voyages by “*Improved Fleet Planning*”. There is possibility hither for charterers to boost the efficiency.

This may be having close relation with the philosophy of "just in time" arrivals. [9]

1.6.12 Cargo distribution for optimization

At superintendence gives more reliable managing of fleet capability and applying of “best practice,” this may be understandable in order to withdraw and decrease ballast voyages by means of enhanced fleet planning. It is surely linked to the philosophy of “just in time” arrivals. [9]

1.6.13 Type of Fuel used

Various alternatives of fuel used is also called as a "CO2 mitigation Method." may help on improving the efficiency of a vessel. However, reaching out this type fuel usually depends on the availability or applicability. [9]

To be able to decrease the desired fuel quantity for implementing an assigning the torch generated, the fuel condition should be increased. [9]

1.6.14 Miscellaneous

While there are several choices accessible, these are not undoubtedly total, and usually depends on area trading area, and possible for claiming the cooperation and supporting a few various business partners considers themselves to be allowed as maximum efficiently.

Those could be viewed as Bulbous bow optimization, Trim optimization, Air Lubrication, or Computer Software to measure fuel consumption, use of renewable energy technology etc. [9]

1.7 "Trim Optimization"

"*The Trim optimization*" is considered as a best practice among the fuel-efficient methods. [9]

The consumption of fuel caused by the shaft power of vessels that enable to trust of the ship utilizing the propeller by overcoming resistance. Changing the trim influence this resistance and provides to improve fuel saving. However, there is not a unique trim for a vessel that is optimum for all speeds, displacements, water depths, leave alone an optimum single value for all ship.

To maintain optimum trim is the main task. There are many tools, such as trim optimization software in the market used by ship operator.

1.7.1 Definition of Trim Optimization

"The trim optimization" is defined clearly is that angel of trim on a specific condition in terms of speed and displacement of a vessel where desired thrust force is lower according to the any induvial angle of trim at that specific condition. [23]

As another definition of *"The Trim optimization"* described as determining the trim angle on certain circumstances such as "displacement and speed" where desired power of shaft of the vessel is less than any individual trim angle at the certain circumstances.

1.7.2 Aim of Trim Optimization

Optimizing ship trim has earned tremendous drive in current years. Earlier, just a few companies considered trim optimization; most companies thought it is neglectable. However, after fuel prices increased and the effectiveness of ships is gaining more awareness, the trim optimization has enhanced more significant.

Vessels are generally adjusted on for a single trim for the entire voyage condition, ordinarily the service speed at design draft. Real running conditions quite often vary significantly. At other speed and draft compounds, setting the trim can usually be used to decrease the hull resistance. [3]

In order to reduce the hull resistance and its effects on the fuel consumption different methods currently used as model tests numerical analysis and Computational Fluid Dynamics methods among the in-service measurement

The propulsion power and hydrodynamic resistance decline and become minimum levels if vessel sails at an optimum trim for a particular displacement, speed, and sea condition. GHG Emissions are decreased, and fuel consumption will be reduced by reduced propulsion power.

Beforehand only a few companies considered on trim optimization; most companies considered that it is neglectable. However, since fuel prices increased and the effectiveness of ships is getting more recognition, the trim optimization has become more critical. There is much saving potential in optimized trim sailing. [3] By means of strict trim optimization software, it is even reasonable to determine the optimum trim during a whole voyage, although some design characteristics or safety components can restrict the ample range of “trim optimization”.

1.8 Literature Review and Field Studies

Trim optimization has emerged as one of the most effective methods of saving both fuel consumption and reducing emissions by vessels when on transit. [24] That the major fuel-saving efficiency through trim optimization is attained through inclining the vessel in water to such a slanted gradients and slope that the waves of water resistance against the vessel are minimized, while the propulsive power is enhanced. Trim has been stated as the difference between the levels of which the aft and forward of a vessel is dipped in water when compared to the level of the forward stern of the vessel. [25] The difference between the levels in which the aft stern and the forward stern are dipped under water is important because it defines the level of hull resistance that a vessel experiences while on motion [26].

The aim is to minimize the propulsion power required for water displacement while the seed and load and speed of the vessel remain constant. In this respect, Illus contends that moving a vessel at 5 -10 centimetres off the optimal trim level can occasion a serious water wave resistance against the vessel, resulting in the vessel being required to operate at high fuel consumption levels so as to attain the same propulsion power it would at the optimal trim level. [27]

Consequently, realizing fuel-saving through trim optimization requires that the vessels after stern and forward stern dipping under water should be calibrated such that they produce the minimum hull resistance possible when the vessel is on motion. According to Reichel, Minchev & Larsen [28], fuel-saving through trim optimization is quite cheap because no need to require any modifications of the shape of hull or the alteration or upgrading of the vessel’s engine. Therefore, through proper ballasting or choosing of the load plan for a vessel, it becomes possible to obtain the right trim optimization, which in turn translates into improved fuel efficiency of the given vessel. [29]

Proper ballasting and load planning ensure the attainment of the proper slanting gradient that optimizes the trim of a vessel and achieves the targeted fuel-saving efficiency is different for different types of vessels. The results of studies undertaken with almost 300 vessels, as presented by Reichel, Minchev & Larsen, indicates that large vessels such as the container vessels, Ro-Ro vessels and tankers have recorded by up to 15% fuel-saving in specific conditions through trim optimization [28].

The focus on the role of Trim optimization in creating fuel-saving efficiency has historically applied a number of approaches. Nevertheless, regardless of the approach applied, the studies done for Trim optimization based on CFD (Computational Fluid Dynamic) and studies based real field data model scale testing (MSC) have demonstrated that indeed, trim optimization works towards enhancing fuel-saving efficiency of the vessels [30]. For example, according to Hochkirch & Mallol, a study undertake to establish the role of trim optimization in creating fuel-saving efficiency applied both the CFD (Computational Fluid Dynamic) and the traditional model scale testing (MSC) to establish if the two approaches would give the same results. [31]

The study conducted by the Military Sealift Command (MSC) focused on one U.S. military vessel for which full-scale sea trials for the identified ship were undertaken and the data of the ship performance such as the propulsion power, speed, and fuel-consumption under different trim angles were recorded. [31]

The study with the same ship was repeated, but this time by applying the FINE™/Marine /Marine CFD computations under both the calm-water powering performance and the turbulent-water powering performance conditions. The results of the study indicated under the optimal trim-angle, “the ranking derived from CFD simulation at model scale agreed very well with model tests”, with the real field data model scale testing (MSC) producing a reduction in water displacement total resistance in motion (RTM) of 0.46%, while the and the CFD computations produced an RTM of 0.48% [31]. The study concluded that both the CFD and the model scale testing produced the same results under the optimal trim-angle in calm-water powering performance, but the results differed slightly under the turbulent-water powering performance conditions.

Another research study by Seok, Kim, Seo & Rhee [32] presents the results of an experimental study conducted to compare the outcome of trim optimization attainable through bow-design improvement by using the real design variation tests field data obtainable under a specific Design of Experiment (DOE) as compared to Computational Fluid Dynamics (CFD) [32]. The study sought to modify the bow of a114K DWT Aframax tanker, with the data of reduced water displacement resistance recorded manually based on the DOE experiment real alteration performance data outcomes, and then compared with the CFD data collected for the vessel both before and after the bow modification and improvement. The results of the study indicated that real DOE field data can be used to determine the parameters necessary for obtaining the best shape of the hull to reduce additional resistance caused by waves just as effectively as the CFD, where the COE "reduction of the added resistance confirmed by CFD analysis was 8%" [32]. The study concluded that COE design variation tests can measure the hull optimization added or reduced wave resistance just as effectively as the CFD simulations.

In conclusion, trim optimization is one of the cheapest ways of attaining fuel-saving efficiency in ships and vessels transport. The existing data from both model scale testing and CFD analysis have demonstrated that with the right optimization of the hull, water displacement resistance can be reduced, and the propulsive power of vessels enhanced. The outcome would be significant fuel-saving efficiency for the vessels.

2 METHODOLOGY

This study is focused on performance and benefits of trim optimization methodologies applied to a high-speed Ro-Ro fleet. In order to evaluate effects of trim optimization, calculated fuel savings results of trim optimization system compared with real field data and analysed statistically to understand if calculated results confirmed by real fuel consumptions of the test vessels.

DNV GL’s Eco Assistant software based on CFD methodology used for calculations of trim efficiency and specifically designed for test vessels installed to all fleet.

The actual field data of 3 sister vessels have been studied in this study. The common particular of these vessels is that they were constructed in a shipyard in Germany with the identical particulars in terms of hull and machinery and other outfitting.

Data gathering of the Test Vessels are provided by means of software from DNV GL’s as so-called Navigator Insight fleet performance monitoring and Eco-Assistant Trim optimization tool.

Studied Test Vessel are operated on the same routes between Turkey to Italy and France. Oldest vessel was built in 2001 and the last one in 2012.

Regarding with the Test High-Speed RoRo Vessels.

- All “Test Vessels” was built at the same shipyard with same technical structure in terms of hull and machinery with same propeller type in the same year as in 2005
- All “Test Vessels” have identical painting technic as SPC antifouling coating
- Engines of the all “Test Vessels” are operated with the specific type of fuel oil supplied by a reputational supplier company with fixed oil specifications
- All “Test Vessels” are the liner vessel which transport same type roro cargo units with almost same loaded capacity as containers on roll trailers, semi-trailers and complete units

- All "Test Vessels" have been managed by a technical management leading roro market in Mediterranean by means of a particular planned maintenance system and monitored with identical software in terms of fleet performance
- All Test Vessels have been kept with only original spare parts during their engine planned maintenance and routine overhauls operations.
- All Test Vessels steamed between the same routes and same waters in Mediterranean Sea. Example of vessels track have been shown in figure 22:

Figure 12 Mediterranean Sea. Example of vessels track

2.1 Limitations and Assumptions

- The geographical area where the Test Vessels are operated in Sea of Marmara, Aegean and Adriatic Sea. The liner route is Istanbul-Trieste- İstanbul, Istanbul-Toulon- İstanbul and Mersin-Trieste -Mersin ports and the duration of the one round trip is almost one week (between 64- 72 hours in normal circumstances for each vessels)

- As one for the crucial parameter of the analysis, the speed over ground is derived as the average speed over ground calculated for each leg of the trip from distance sailed divided by duration of each leg of routes in respectively.
- Measurement sensors have not been installed to the Test Vessels such as sensors for torque measurement, hence power produced for thrust can be measured from fuel consumption result of the test vessel and engine recognition of the factory.
- SFOC curve made in manufacturing plant acknowledgment test of the engine was done with a fuel of 42274 kJ/kg. And the real LCV of the fuel that all vessels in address are expending is 40200 kJ/kg. In this manner, SFOC Curve redressed agreeing to Lower Calorific Value of the fuel which vessels are devouring.
- Due to all “Test Vessels” are the sisters vessels with particular specialized arrangements and working beneath same sailing conditions and due to data of tall number of voyages has been monitored which is able to covering related seasons of the assumed years, the other uncontrollable factors such as wind and sea states ignored. In this manner, other measurement parameters such as wind and water profundity are not included in this study.
- The used data of the test vessels belongs to two periods. The first period is called “Pre-period in which all vessels have a dry dock hull and propeller maintenance painted with same hull coating technology at the same of the month of the same year. This period also where the data collection and analysing made without Trim optimization. The second period is called “post-period” in which all vessel have dry dock hull and machinery maintenance with same hull coating technology one year later after “Pre-period “where the all vessel has started to use trim optimization methods. Thus, it is provided that the critical operational factors of the energy efficiency operations of the vessels such as propulsion system and vessel total resistance minimized to see the effect of the trim optimization on fuel-saving results of the test vessel.

2.2 Application of the Methodology.

In this study, three-vessel have been selected among the twelve-sister Ro-Ro vessels. The reason why three vessels deeply are focused among of those twelve sister Ro-Ro vessels is the dataset used in analysing to determine the effect of the trim optimization.

A specific Trim optimization software has been developed for the 12-sister roro vessel based on computational fluid dynamic method and installed to all of those 12 sister vessel with a user -friendly interface. Since November 2017, 2465 Trim optimization event have been created by the all vessels.

Those 2465 of entries made by vessels have been investigated and analysed and best three of the 12 sister vessels have been selected accordingly due to their dry docking and trim optimization starting periods are matched.

The used dataset of the test vessels belongs to two periods. The first period is called "Pre-period in which all vessels have a dry dock hull and propeller maintenance painted with same hull coating technology at the same of the month of the same year. This period also where the data collection and analysing made without Trim optimization. The second period is called "post-period" in which all vessel has dry dock hull and machinery maintenance with same hull coating technology one year later after "Pre-period "where the all vessel has started to use trim optimization methods. Thus, it is provided that the critical operational factors of the energy efficiency operations of the vessels such as propulsion system and vessel total resistance minimized to see the effect of the trim optimization on fuel-saving results of the Test Vessel.

Speed and displacement corrections defined by ITTC Admiral formula [34] have been applied to all data belong to the Pre-Period and Post-periods for increasing accuracy of the tested vessels' statistical results while the data set gathered.

In order to obtain any meaningful development on loss of speed and consumption of fuel decrease by Trim optimization method, the following procedure is used:

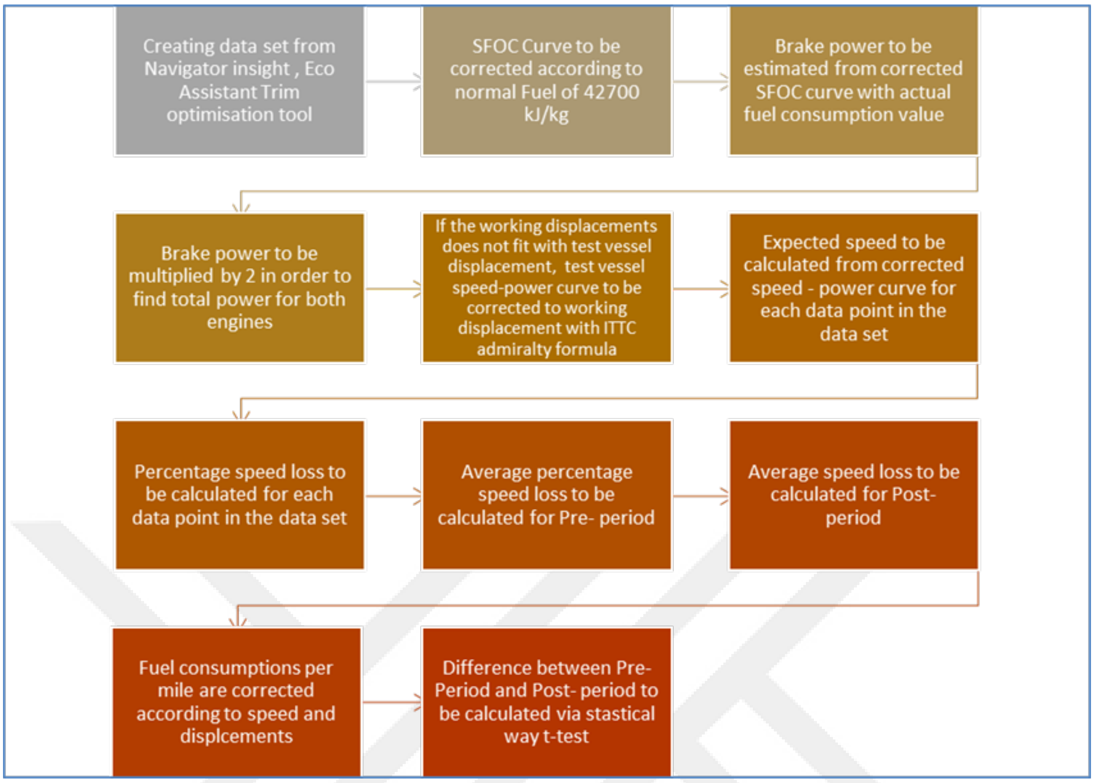

Figure 13 Methodology overview

2.3 Ship Particulars of "Test Vessels"

Table 5 Ship particulars of the "Test Vessels"

PARTICULAR	VESSEL 1	VESSEL 2	VESSEL 3
BUILT YEAR	2005	2005	2005
GROSS TONNAGE	29004	29004	29004
NET TONNAGE	8702	8702	8702
DWT SUMMER LOAD	11636	11636	11636
DWT DESIGN DRAUGHT	9481	9481	9481
LIGHT SHIP	9041	9041	9041
BREADTH	26 mtrs	26 mtrs	26 mtrs
LENGTH OVER ALL	193 mtrs	193 mtrs	193 mtrs
LENGTH BETWEEN PERP.	182,39 mtrs	182,39 mtrs	182,39 mtrs
DEPTH TO MAIN DECK	8.6 mtrs	8.6 mtrs	8.6 mtrs
DEPTH TO UPPER DECK	16.7 mtrs	16.7 mtrs	16.7 mtrs
DRAUGHT(SUMMER LOAD)	7,00 mtrs	7,00 mtrs	7,00 mtrs
DRAUGHT(DESIGNED)	6,45 mtrs	6,45 mtrs	6,45 mtrs
SERVICE SPEED	21.5 KN	21,5 KN	21,5 KN
MAIN ENGINES	MCR 16200 KW	MCR 16200 KW	MCR 16200 KW
LANE METERS	3735	3735	3735
CLASSIFICATION	DNV + 1 A1 GENERAL CARGO CARRIER RO-RO	DNV + 1 A1 GENERAL CARGO CARRIER RO-RO	DNV + 1 A1 GENERAL CARGO CARRIER RO-RO
BOW THRUSTER	1400KW(1900 HP)	1400KW(1900 HP)	1400KW(1900 HP)

3 RESEARCH AND FINDINGS

3.1 Software for Trim Optimization (Eco-Assistant)

DNV GL’s Eco-Assistant Trim optimization tool has been installed to Test Vessels studied in this Thesis.

“The ECO-Assistant “is a friendly user software tool that delivers the optimum trim angle for a specific ship associated with the operational input of speed, displacement, and optionally depth of sea. The essential element of the "ECO-Assistant" is the complete information of vessels particular resistance information based on computational fluid dynamic

The ECO-Assistant can be seen as a product consisting of two parts:

1. A comprehensive database of ship-specific data for the different operating conditions.

2. A user interface that makes the optimum trim information available to the crew on board the vessel in a simple format.

This ECO Assistant can be installed on any computer on the vessel, which makes the installation by very nature much more cost-effective than sensor-based trim optimization tools.

The Eco-Assistance software was installed all reference Model Test Vessels, which are the main real field data sources in order to understand whether CFD calculations work on Fuel Saving.

Below are the steps of the CFD calculations used on Eco-Assistant software developed according to the studied Test Vessels in this thesis.

Visualization of geometry generation at the example of the bulbous bow of the Model Ro-Ro Vessel

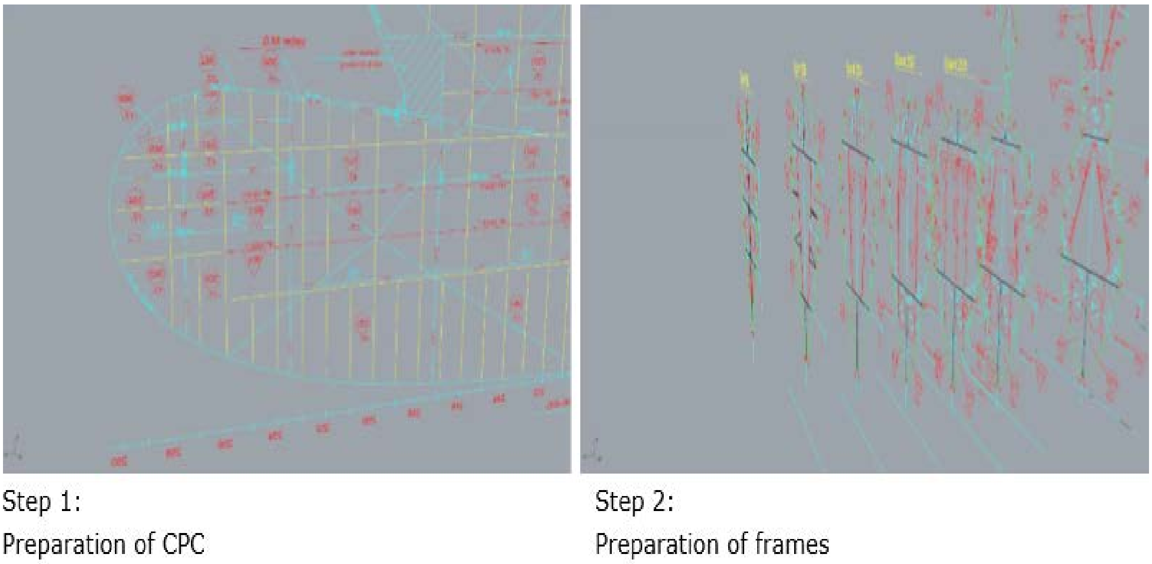

Figure 14 Geometry generation of Bulbous bow of the test vessels, Step 1 & Step 2

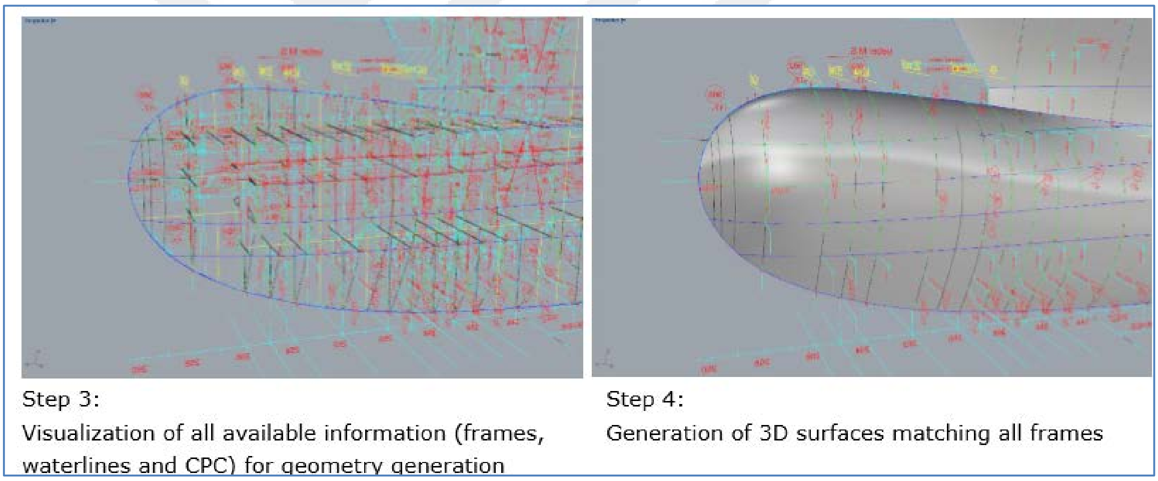

Figure 15 Geometry generation of Bulbous bow of the test vessels, Step 3 & Step 4

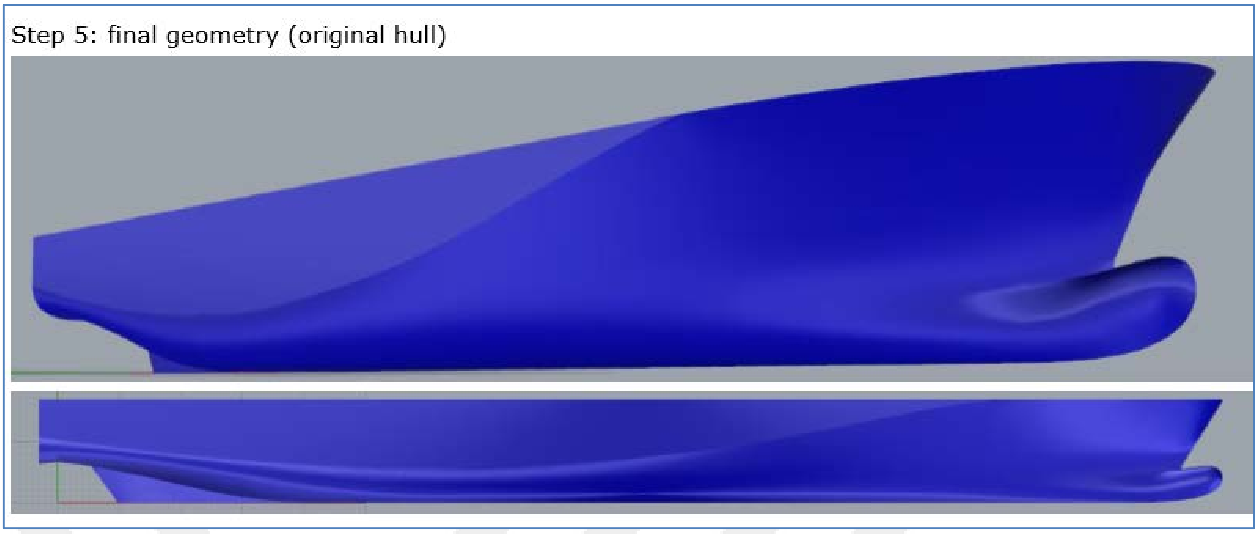

Figure 16 Final Geometry of the original hull

3.1.1.1 Domain size and grid generation:

An unstructured full-hexahedral meshing tool is used for grid generation. All calculations are carried out for a half model only, i.e. symmetry in the y-Plane was applied. The domain size was chosen to account for unrestricted and deep water. Standardized grid setup was used, i.e. cells are clustered around the ship hull with a base cell size relative to the length on the hull surfaces. Near areas with expected large changes in flow, the grid is refined. To accurately capture the surface, the grid is further refined in z-direction close to the expected interface location. For accurate capturing of flow gradients in the boundary layer, extrusion cell layers normal to the ship hull surfaces are generated with a target y+ within the acceptable limit. The following pictures show the resulting mesh discretization of the 3D hull surface

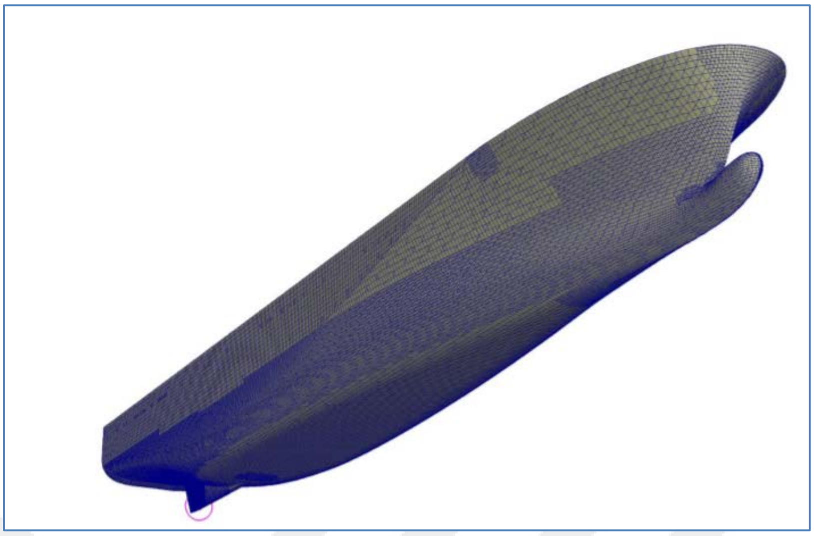

Figure 17 mesh discretization of the 3D hull surface

3.1.2 Computational setup:

3.1.2.1 Ship motions:

- For all CFD computations the ship model is free to heave and trim, i.e. the heave and pitch motions are solved.
- Heel, yaw and sway motion are fixed, and the forward translation is imposed by the computational setup.
- To deal with start-up problems as sloshing, spray and wave reflections a sinusoidal start-up ramp is used.

3.1.2.2 Free surface effects:

- The free surface is captured by a Volume of Fluid (VoF) approach. This requires the solving of an additional transport equation for the fraction of fluid in each cell. A value of one means that the cell is occupied completely by the higher density fluid (e.g. water in a water and air mixture).
- Fluid properties such as density and viscosity are calculated as a weighted average based on the volume fraction of each fluid in each cell. If not otherwise specified all calculations are carried out as 2^{nd} phase-calculations considering free surface effects.

3.1.2.3 Effects of the working propeller:

- The effects of a working propeller are captured by a so-called Body Force or Actuator Disk method. Hereby the thrust of the propeller is modelled by volume forces which are applied in the propeller disk or rather a cylinder with the diameter and approximate thickness of the propeller. As a result, effects such as the stream contraction and flow acceleration (both axial and rotational components) can be captured, while effects such as hub or tip vortices cannot. Parameters such as the propeller torque and the relative rotative efficiency (ηR) cannot be determined.
- The Body Force method (without considering rotational flow components) is the standard method. Symmetry about the x-z-plane is maintained and self-propulsion is achieved by balancing the integrated forces.
    1. Fluid properties:
    2. For full scale calculations and predictions in case of sea going vessels: 15°C, sea water ($\rho Water = 1025\ kg/m^3$, $\nu = 1.1873e\text{-}6\ m^2/s$) o Turbulence closure
    3. A k-ω-SST turbulence model with wall functions is applied as standard turbulence model. Depending on the respective implementation, the required dimensionless wall distance y+ is determined.
    4. For accurate capturing of flow gradients in the boundary layer, extrusion cell layers normal to the ship hull surfaces are generated with a target y+ within the acceptable limits.

3.1.3 Fuel savings potentials:

The following samples are valid for the original hull configuration. Slow steaming with 13kn (usage of 1 ME only): At 5.5 m draft:

- Retrim by 0.5m from level draft to -0.5m bow down saves 5.4% power and 0.6 t/day fuel per vessel

- Retrim by 1m from 0.5m stern down to -0.5m bow down saves 10.4% power and 1.2 t/day fuel per vessel.

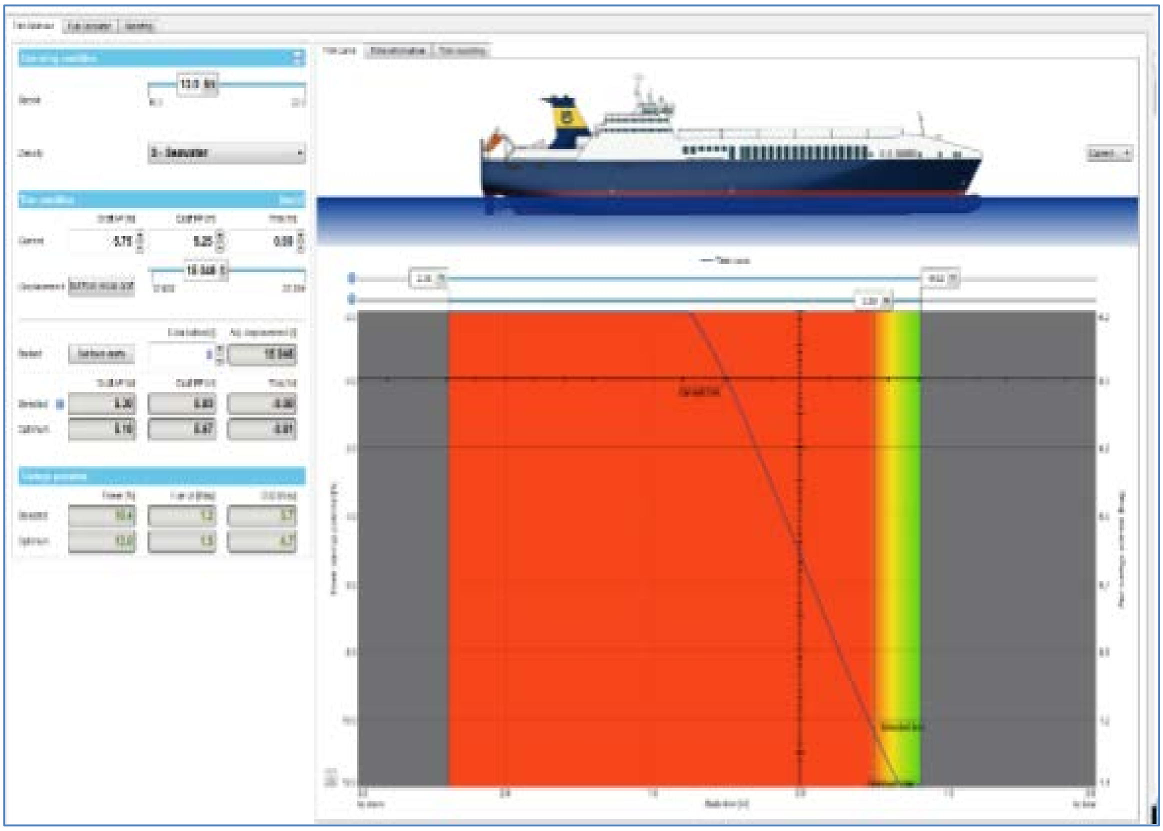

Figure 18 Sample of screen shot of Eco-Assistant software user screen for Test roro vessels

Normal operation at 19.5 kn (both ME operating) At 5.5 m draft: Retrim by 0.5m from level draft to 0.5m stern down saves 1.2% power and 0.5 t/day fuel per vessel

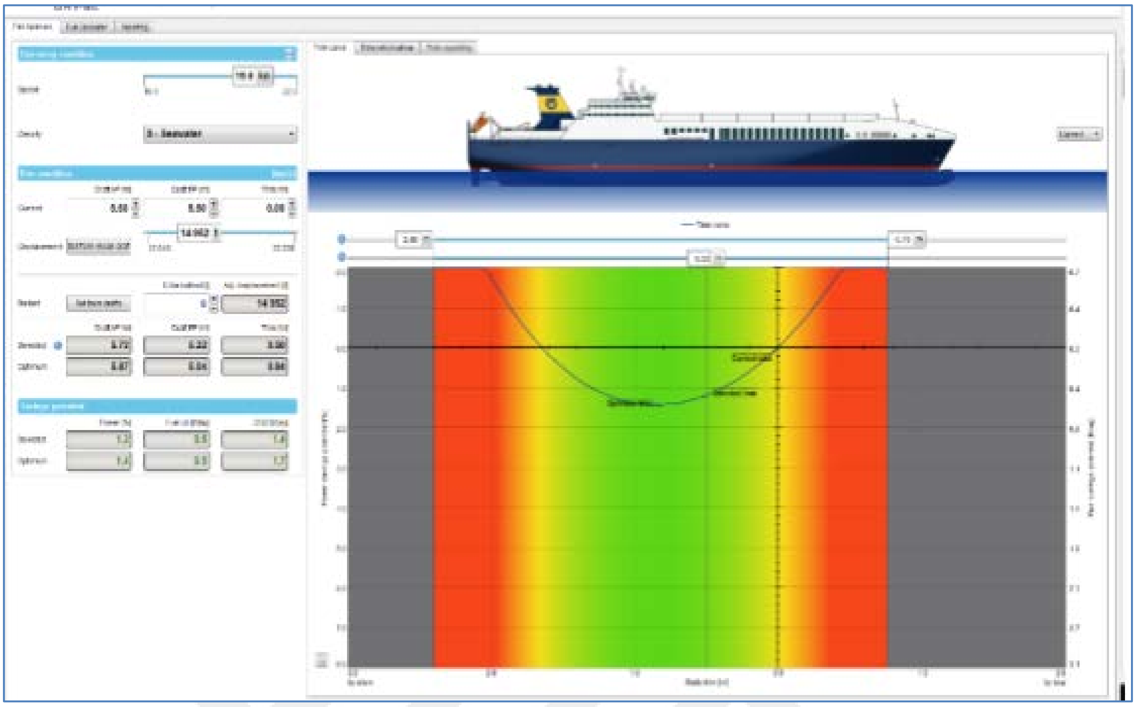

Figure 19 Sample of screen shot of Eco-Assistant software user screen for reference roro vessels

3.1.4 Results: Plausibility check:

The comparison of the calculated bow wave shape with real pictures at below shows a very good agreement.

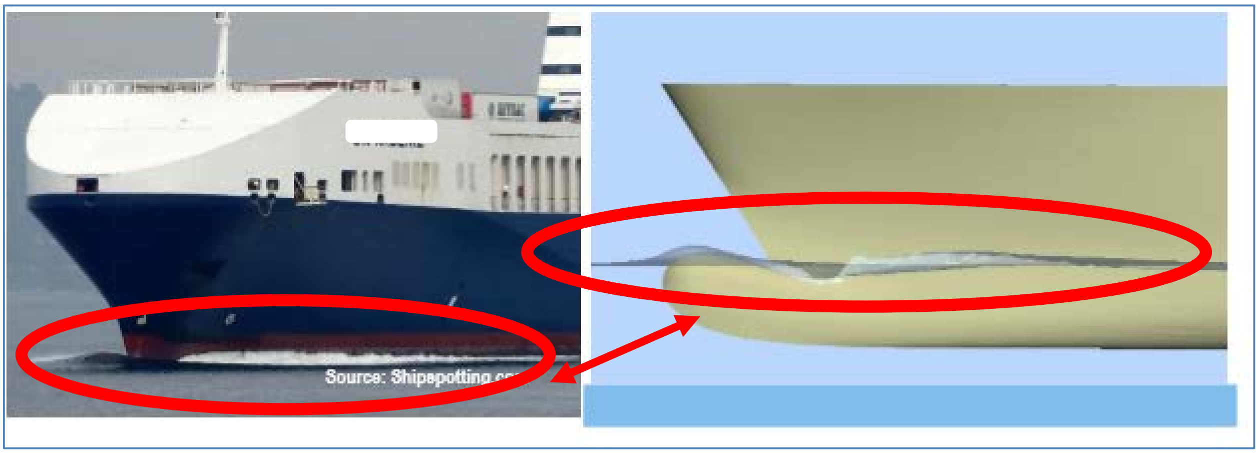

Figure 20 Calculated bow wave via CFD vs Real Bow wave shape

This study based on evaluating CFD calculations of Trim Optimization with real-field data. In order to carry out analysis, easy to use software installed to all vessels and trim optimization trainings carried out on all vessels in order to be sure that the idea of trim optimization and using of software tool well understood by crew. Below methodology followed to carry out if implementation of CFD calculations created extra efficiency through fuel saving.

1- Chief Officer reads draughts values at the end of the loading operation and enters to Trim Optimization Software.

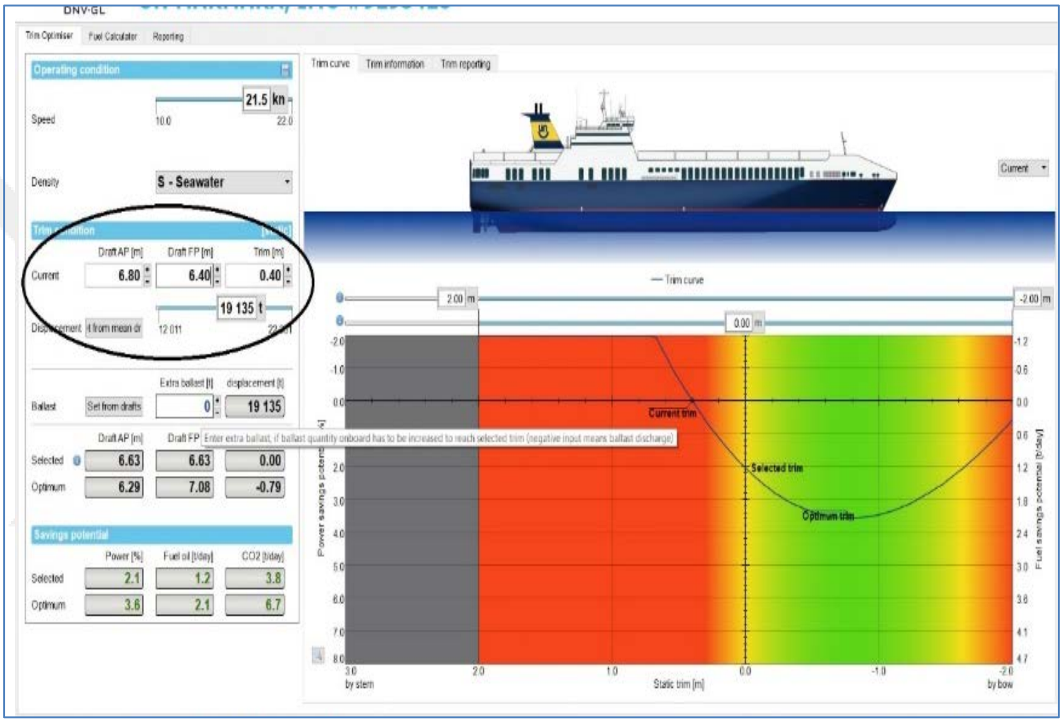

Figure 21 Sample of screen shot of Eco-Assistant software user screen for reference roro vessel

2- Trim optimization software calculates optimum draughts and inform user how much fuel saving potential is possible if vessel's draughts can be changed to optimum draughts.

3- Chief Officer uses Stability Software to test how vessel can be trimmed under current loading and stability conditions. In most cases it is not possible to reach optimum draughts

Figure 22 Sample of screen shot of Eco-Assistant software user screen for reference roro vessels

But Chief Officer tries to approach optimum draughts as practicable as possible. In below sample, even optimum draughts requires to trim vessel 80 cm to forward but vessel could

Only trimmed 10 cm to forward. If vessel could be able to reach optimum draughts, it would be possible to save 2, 1 tons of fuel daily. But vessel could trim vessel to 10 cm forward by discharging 300 tons of ballast water and created 1,9 tons of fuel saving daily which is a result of CFD calculation.

4- Vessel reports actual draughts with Navigator Insight reporting software for every events like departure, noon, and arrival reports.

5- Draught information which are received with event reporting, compared with CFD results to evaluate how trim optimization could be implemented and how much trim potential remaining.

3.2 Navigator insight fleet performance manager software

The Navigator Insight system has been formed by DNV GL to support ship owners and managers to provide quality of data of each vessel in the fleet for particular fleet performance review. "The integrated system" presents an integrated module for structured and set on reporting of data with smart validation that immediately alerts officers of possible reporting mistakes or unreasonable data. The event-based reports are logged on the onshore server for later evaluation. [33]

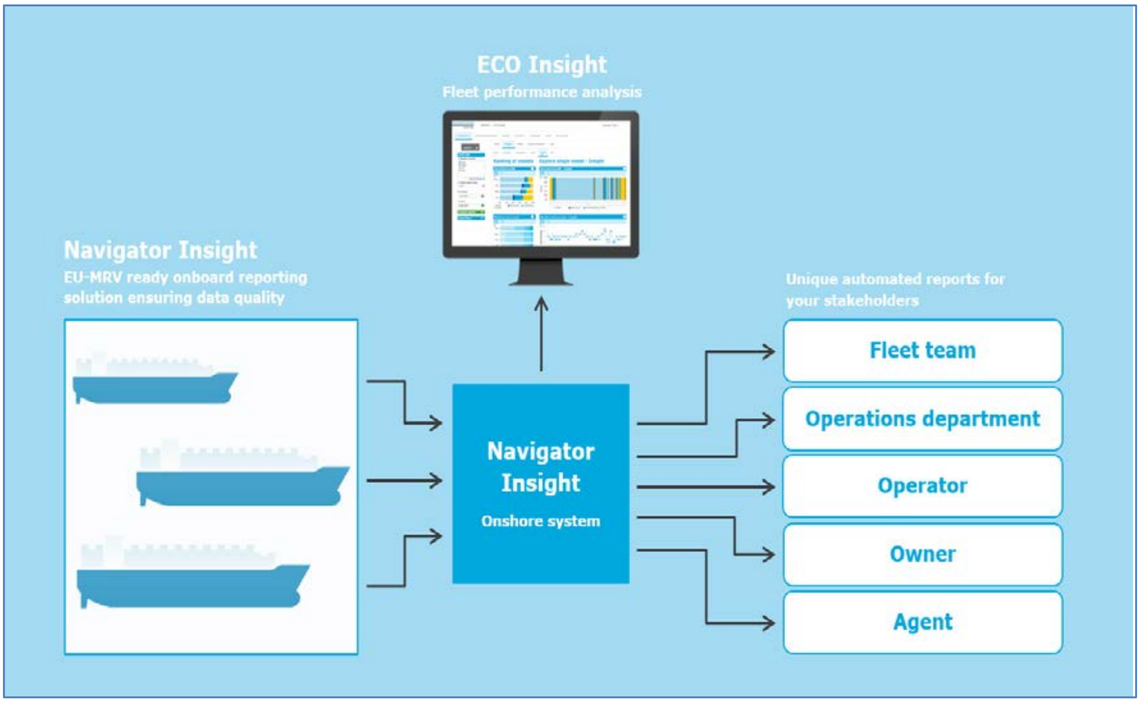

Figure 23 Navigator Insight and ECO Insight for streamlined reporting and unique operational insight [33]

On thesis data of the test vessels such as Distance sailed, voyage number, duration of voyage, consumption of the relevant voyages etc. have been gathered throughout of this software.

3.3 ISO 10930 Dry docking Performance

Below methodology has been followed which is taken from ISO 19030 dry docking performance indicator calculation methodology and adapted to analyse effect of the trim optimization.

"The intention of ISO 19030 is to guide practical approaches for measuring the changes in vessel-specific hull and propeller performance and to determine a set of appropriate performance indicators for hull and propeller maintenance, renovation, retrofit projects. The practices are not designated for correlating the performance of vessels of various types and sizes (including sister ships) nor to be used in a supervisory structure" [12]

ISO 19030 consist of three parts:

The primary section describes common sources on measuring differences in the performance of the hull and propeller and describes the gathering of performance information.

The second section explains the default approach to measure variations in the performance of the hull and propellers and for determining the performance KPIs. It additionally leads to the essential efficiency of individual performance indicator.

The third section paints options to the default method. Some of the methods have a result in lower efficiency but improve the applicability. On the other hand, some other method may outcome in the identical or bigger total accuracy but involve factors which are not yet broadly accepted in industrial shipping.

3.3.1.1 Data retrieval

Section two of the ISO 19030, defines that the data shall be tracked concurrently at a repetition if one signal every 15 seconds (0.07Hz) or settled by a data acquisition system (e.g. data logger),

The section 3 of the standard grants the determinations to be recorded short periodically (e.g., noon data) if a system for data collection at this frequency is not available. Section 3 of the standard needs the following specifications:

The data sampling rate shall remain constant over the full measurement period (Pre-Period and Post- Period), but for changes created by time-zone change; Primary measurement parameters (speed, power from either shaft torque and rpm or fuel consumption) shall be averaged over the period;

Average values are used for a specific time of period such as speed, power from both for shaft and torque as the primary measurement

Secondary measurement parameters shall, to the extent possible, be collected at the same sampling rate as the primary measurement parameters, or no less frequently than one signal per day. Except for wind and draught, those values shall be short-term average values (e.g., averages over one minute) held at the point in time the observation is obtained.

Where there is no opportunity to collect the data automatically, the alternative way of gathering data could be possible as well as manually. It introduces an uncertainty partly due to the increased possibility of human error against error possibility in automated data collection systems, but also due to the necessity of reducing sampling frequency.

3.3.1.2 Performance Indicators

The Standard defined the performance indicator shows effects and determinations of vessel-specific varieties of the "hull and propeller" maintenance or any other new design or application such as retrofits or trim optimization.

3.3.1.3 Performance Indicator 1 - Dry-docking performance

The following figure 23 presents the varieties in performance of “hull and propeller” after dry docking in comparison by components of first dry dockings' performance. Where data or measurements are available to determine the effectiveness of the dry-docking

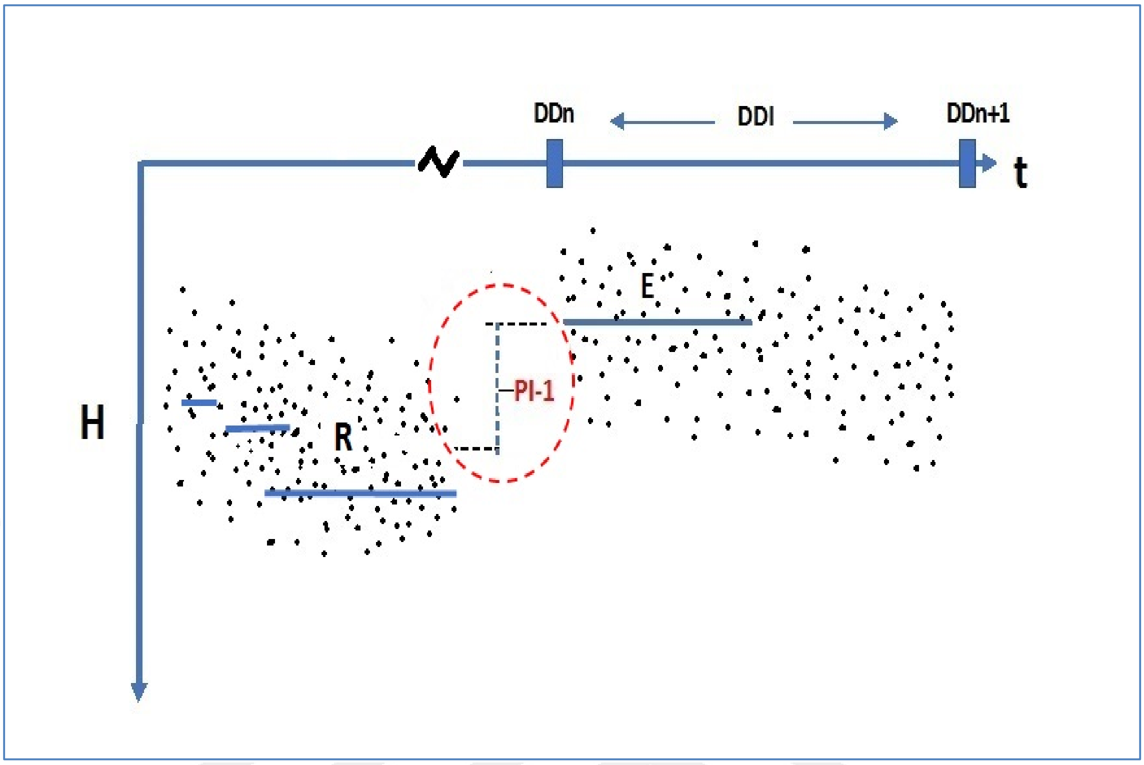

Figure 24 Dry-docking Performance (Source: ISO 19030)

Where:

H	“Hull and propeller performance”
t	Time
DDn	Current dry-docking
DDn+1	Next dry-docking
DDI	Dry-docking interval

R Pre- period: average “hull and propeller” performance following past out-dockings

E Post- period: hull and propeller performance following present out-docking

PI-1 Performance Indicator 1: “Dry-docking performance

The cycle following directly following the latest "dry-docking" is the "Post- period". The periods following directly after pervious dry-dockings are the Pre- periods. All periods are to be of the same length of one year.

3.3.1.4 Indicator 2 – In-service performance

To circumscribe solutions for the effectiveness of the "hull and propeller" remains below the waterline, so as hull layers or any new method (e.g., Trim optimization) used over the time of dry-docking period, the average variation in performance of "hull and propeller" belongs to the period remain "out-docking" to the end of" dry-docking" period.

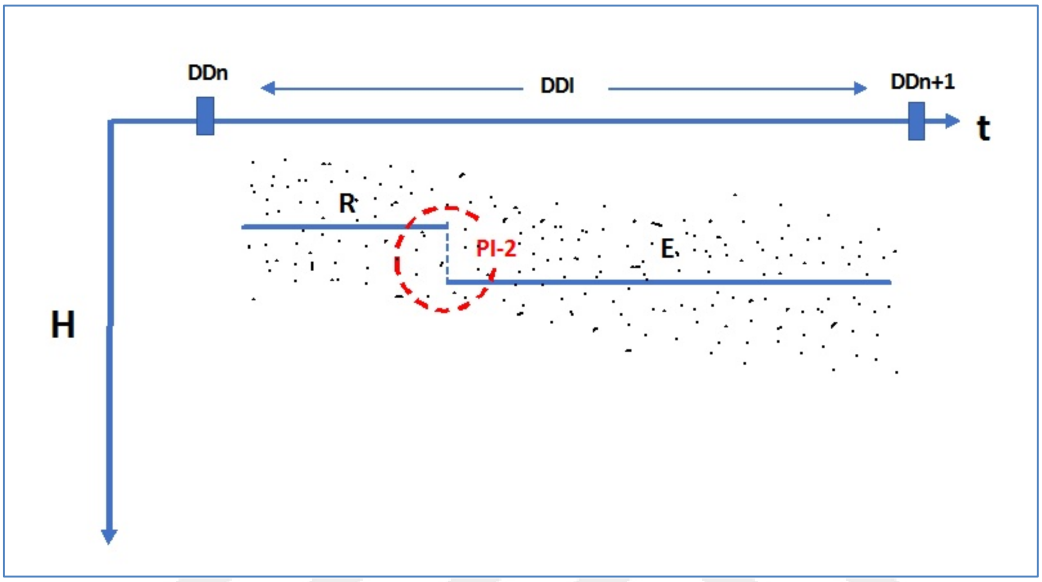

Figure 25 In-Service Performance

Where:

H	“Hull and propeller performance”
t	“Time”
DDn	“Current dry-docking”
DDn+1	“Next dry-docking”
DDI	“Dry-docking interval”

R “Pre- period”: “hull and propeller” performance following current out-dockings

E “Post- period”: avg. “hull and propeller” performance over remainder of dry-docking interval

PI-2 Performance Indicator 2: In-service performance

The cycle succeeding directly afterwards the latest dry-docking is the “Pre-period”. The period following the reference period until the end of the same dry-docking period is the “Post-period”. The “Pre-period” and the “Post-period” shall both be of minimum one year.

3.3.1.5 Indicator 3 – Maintenance

The determined variation in hull and propeller performance from the commencement of the dry-docking period to a successful average at a favoured course when the identical interval can be used as a starter for underwater maintenance of hull and propellers, including propeller and hull brushing.

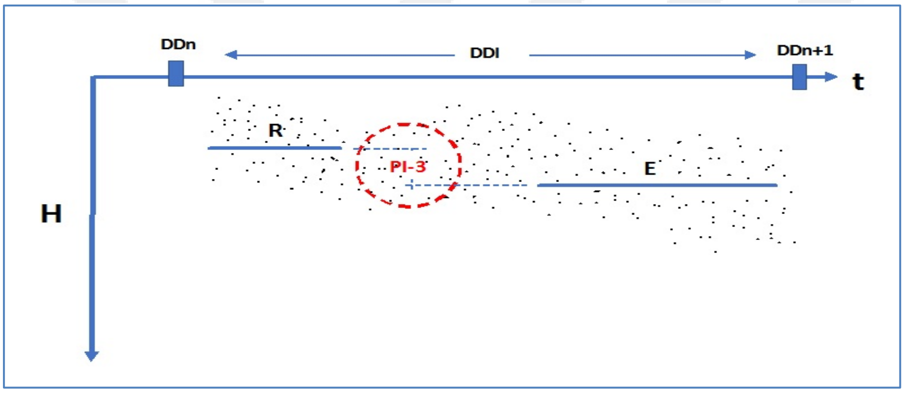

Figure 26 Maintenance Trigger (Source: ISO 19030)

Where:

H	“Hull and propeller performance”
t	“Time”
DDn	“Current dry-docking”
DDn+1	“Next dry-docking”
DDI	“Dry-docking interval”

R “Pre- period”: hull and propeller performance following present out-docking

E “Post -period”: moving average hull and propeller performance at any chosen time

PI-3 Performance Indicator 3: Maintenance trigger

3.3.1.6 Indicator 4 – Maintenance Effect

The change in hull and propeller performance estimated before and after a preservation event can be used to ascertain the effectiveness of a specific maintenance project which has taken place during period within the measures, covering propeller and/or hull brushing.

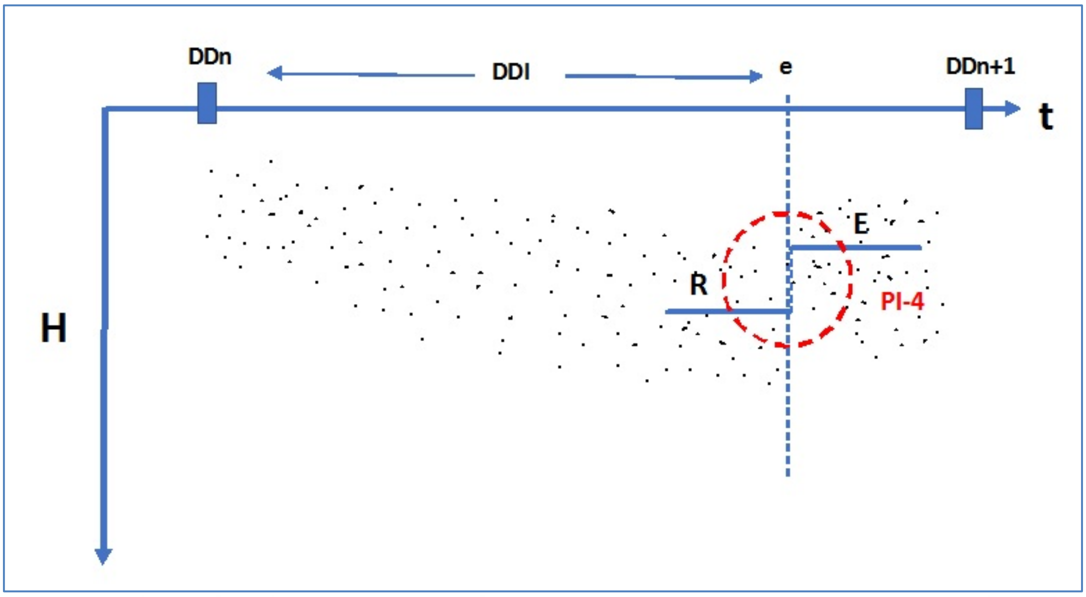

Figure 27 Maintenance Effect (Source: ISO 19030)

Where:

H	"Hull and propeller performance"
t	"Time"
DDn	"Current dry-docking"
DDn+1	"Next dry-docking"
DDI	"Dry-docking interval"
E	"Maintenance event"

R "Pre -period": "hull and propeller" performance before maintenance event

E "Post -period": "hull and propeller "performance after maintenance event

PI-4 Performance Indicator 4: Maintenance effect

3.3.2 Performance Values, (PVs)

For each individual information spot at the adjusted information set, a performance value shall be calculated. The whole of the corrected data set and performance value PVs are related to the provided data set.

The loss rate of the speed matched to a specific speed, and power relationship is named as Performance value (PVs)

3.3.3 Determination of reference conditions

The reference conditions are identical for all performance indicators, and all are met when concurrently.

Delivered power, within the scope of power values included by the available speed-power reference curves. Displacement has to be within +-5% for the available speed. power reference. curves,

Absolute rudder angle value is smaller than 5 degrees, in case that delivered power is determined by the method described in Annex C of the standard, the expected transmitted power must be within the scope of the values included by the available SFOC reference. curve.

3.4 Dry-Dock History of Test Vessels

Three ships used for trial purposes were dry-docked in the same shipyard and similar periods (see Table 6).

Table 6 Dry-docking History of Test vessels

Vessel Name		DDn+1	DDn+2
VESSEL 1	Date of Drydock	29.03.2015	29.12.2017
	Shipyard	GEMAK	GEMAK
	Blasting	SA 2 %100	Spot %5
	Hull Coating	Foul Release Coating - Advanced	1 Full layer Foul Release
	Trim Optimization in use after DryDock	NO	YES
	Engine Overhaul	NO	NO
VESSEL 2	Date of Drydock	16.05.2015	15.01.2018
	Shipyard	BESIKTAS	GEMAK
	Blasting	SA 2 %100	Spot %5
	Hull Coating	Foul Release Coating - advanced	1 Full layer Foul Release
	Trim Optimization in use after DryDock	NO	YES
	Engine Overhaul	NO	NO
VESSEL 3	Date of Drydock	2.06.2015	19.02.2018
	Shipyard	BESIKTAS	GEMAK
	Blasting	SA 2 %100	Spot %5
	Hull Coating	Foul Release Coating - Advanced	1 Full layer Foul Release
	Trim Optimization in use after DryDock	NO	YES
	Engine Overhaul	NO	NO

Dataset is created by means of gathering unprocessed data of all test vessel from the company's particular software reports such as noon report, arrival, and departure reports "Energy Efficiency Operational Index" reports by using Navigator Insight Only and Eco Assistants Trim optimization software's data of the voyages performed in routine circumstances involved in the study. Some trip on which had engine breakdown or any unforeseen suspension on program producing irregular consumptions of fuel are not included.

Dataset includes following information:

Vessel name: Mentioned as test vessel in this thesis

Voyage Number: Voyages are consisting of two trips completed by each test vessel (e.g., steaming on Pendik-Trieste-Pendik line; the First trip of the specific voyage is performed from Pendik to Trieste and second trip is the Trip completed from Trieste to Pendik)

Docking cycle: Data referring to dry-docking period for intended voyage (e.g. DDN refers the dry-docking in which coating applied but trim optimization has not done after out docking, DDN+1 refers to the dry-docking in which coating applied and Trim optimization has been started to apply by all test vessels)

Voyage between ports: Report on voyage between which ports in order to recognize travelled distance.

Displacement: Real loaded displacement of vessel for each trip of the voyage

Total fuel consumption for a specific voyage: Sum of the fuel consumption of each trip of the voyage.

Duration of voyage: the sum of the duration of each trip for the intended voyage

Average fuel consumption per hour for the voyage: Sum of the average fuel consumption per hour for each trip of the specific voyage Calculated by means of dividing the average consumptions of each trip by the duration of the associated duration of subject trip .

Total sailed distance in Nm: Sum of the sailed distance of each trip of the voyage.

Average speed for the voyage (in knots and m/s): Average speed in knot calculated by dividing sailed distance to duration, and average speed in m/s calculated by multiplying knots to 0,5144 as a conversion factor.

Average fuel consumption per mile of the voyage: Calculated by total consumption to sailed distance in Nm

Average consumption per engine in kg: All test vessels have two engines and average consumption per hour divided by two in order to find each engine's consumption. Due to the company's reporting system for fuel consumption in metric tons, it multiplied with 1000 to find consumption in kg. Then corrected to normal fuel of 42700 kJ/kg due to actual fuel's lower calorific value was 40200 kJ/kg.

Data filtered according to the +- 5% for the displacement differences in order to evaluate the identical value of displacements as an operational factor o displacement for any voyage which is not within the range specified above, have not included.

The engines' Specific Fuel Oil Consumptions curves based on the actual test is corrected in-shop test record since through "ISO 346-1:2002" afterward it adjusted for standard fuel of "42.700 KJ/Kg" according to following formula and derived new SFOC Curve.

$$SFOC_{LCV\ corr.} = \left(\frac{SFOC\ x\ LCV_{nor.fuel}}{LCV_{test\ bed}}\right) \tag{10}$$

Where;

SFOC (LCV CORRECTED) : "Corrected SFOC acc. to standard fuel of 42700 kJ/kg"

SFOC : "SFOC value given is shop test report of the relevant engine"

LCV (NORMAL FUEL) : "42,7 MJ/kg"

LCV (TEST BED) : "42,274 MJ/kg"

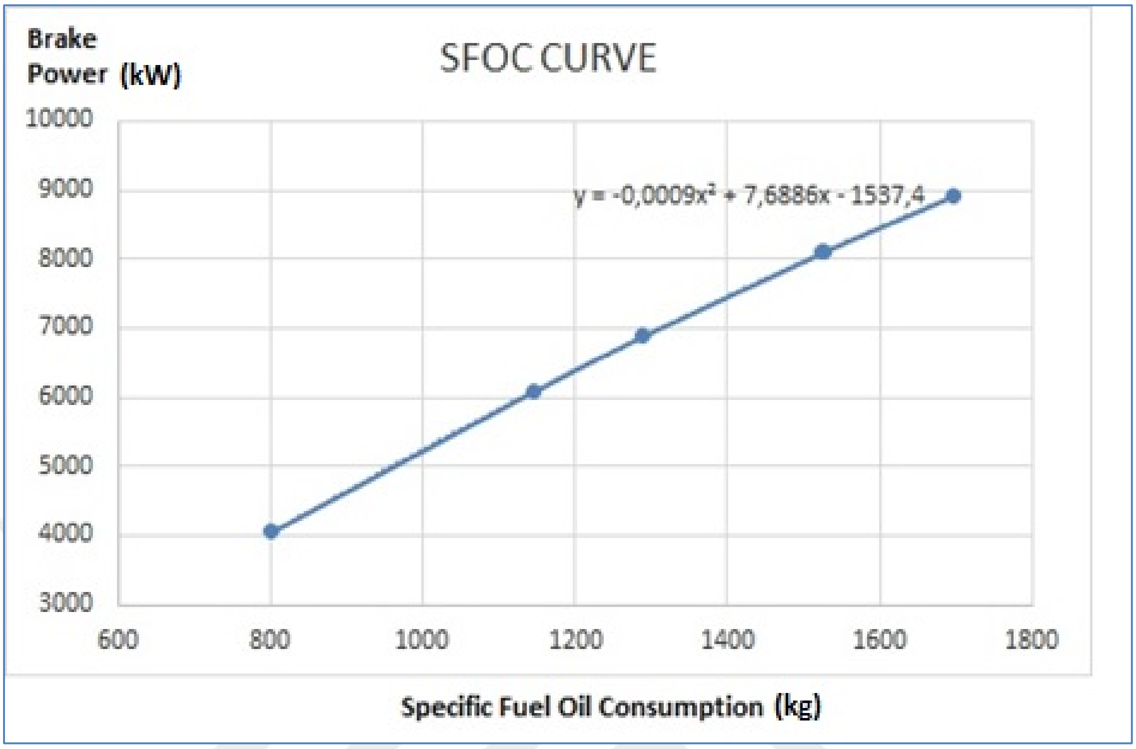

Figure 28 SFOC Curve of MAK 9M43 engines

Transported power of single engine approximated for individual input point based on predictions for "brake power" "P_B" from an engine specific SFOC reference curve prescribed in "Annex D" of Part 2 of the standard.

$$P_B = f\left(M_{FOC} \text{ x } \frac{LCV}{42{,}4}\right) \qquad (11)$$

Where:

M_{FOC} : "Mass of consumed fuel oil by main engine (kg/hour)"

LCV : Lower calorific value of fuel oil (mJ/kg)

f : SFOC reference curve (Corrected with ISO and normal fuel of 42,7 MJ/kg

To be able to calculate exact transmitted power of both engines, the power is multiplied by two

Test forecasts is available for "18.557,6" tons displacement value. For all vessels, a adjusting factor "(ΔVoyage / ΔModelTest)2⁄3" is applied to the Speed and Power curve, according to ITTC displacement reconstruction methodology.

On the adjusted transmitted power of engines, predicted speed measured for any data spot from speed and power reference curve

$$V_e = f \times P_b \quad (12)$$

Where;

V_e : Expected Speed

F : Speed-Power Curve

P_b : Delivered power of both engine

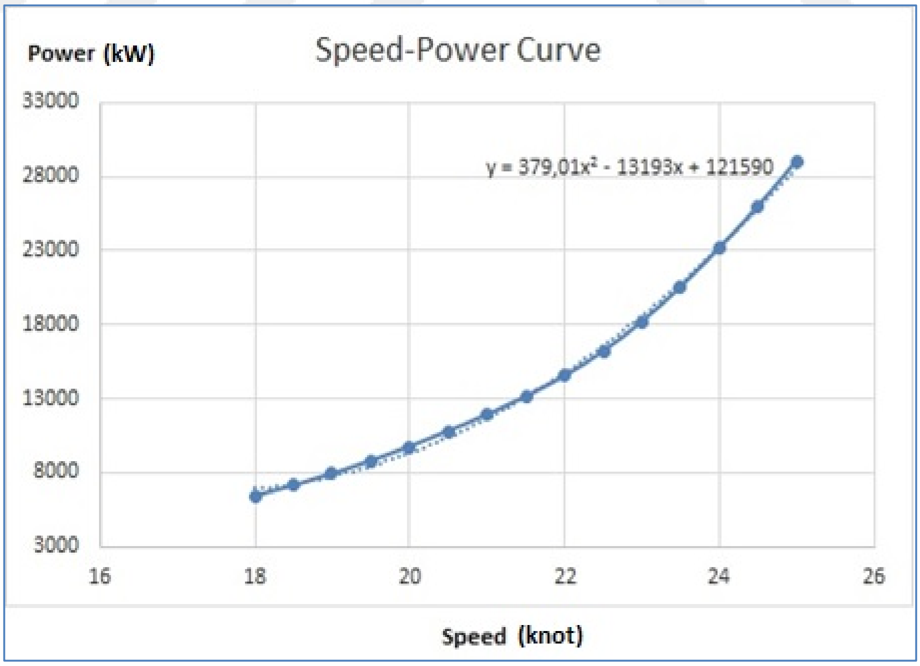

Figure 29 Speed-Power Curve of test vessels from model test report

The rate of speed loss that is prescribed by the "ISO19030" as a performance value , estimated for every single data point on the adjusted data set..

The portion of the speed loss is determined as the corresponding variance in percentage among the estimated speed and required speed with the following formula:

$$V_{d=100\,x\left(\frac{V_m - V_e}{V_e}\right)} \qquad (13)$$

Where;

V_d : Percentage speed loss

V_m : Measured Speed

V_e : Expected Speed

The average percentage speed loss over the reference period(s) calculated as:

$$V_{d,ref} = \frac{1}{k} \sum_{j}^{k} \frac{1}{n} V_{d,j,i} \qquad (14)$$

Where

k "number of reference periods"

j "reference period counter"

n "number of data points in the processed data set under reference conditions in the reference period "j"

i counter of data points in reference period "j"

$V_{d,j,i}$ "percentage speed loss for data point i in reference period "j"

$V_{d,ref}$ "average percentage speed loss over the reference period(s)"

average rate of loss of speed overhead the evaluation period $V_{d,eval}$ determined as:

$$V_{d,eval} = \frac{1}{k} \sum_{i}^{j} \frac{1}{n} \sum_{i}^{n} V_{d,eval,i} \quad (15)$$

Where

n "number of data points in the processed data set under reference conditions of the Post period"

$V_{d,eval,}$ "percentage speed loss for data point i in a data set of the evaluation period"

$V_{d,eval}$ "average percentage speed loss in data set of the evaluation period"

The difference in the average speed loss in the "Pre- period(s)" and the average speed loss in the" Post period(s)" is described as a performance indicator, PI, and is determined according to following equalization:

$$k_{HP} = V_{d,eval} - V_{d,ref} \quad (16)$$

Where

$V_{d,eval}$ "average percentage speed loss in data set of the evaluation period "

$V_{d,ref}$ "average percentage speed loss over the reference period(s)"

$k_{HP} = V_{d,eval} - V_{d,ref}$ "Performance indicator, PI"

To be able to assess differences in fuel consumption, average fuel consumption per mile value of "Pre-period(s)", and "Post period(s) measured from the data set.

New table created for each indicator from the data set in order to make fuel consumption comparisons between Pre-Period and Post period as shown on the below table 7

Table 7 Sample result table

	Unit	Reference	Evaluation	SPEED CORRECTION TO POST-PERIOD	DISPLACEMENT CORRECTION TO POST-PERIOD
Sample Size	**pcs**	46	44	44	44
disp total	**tons**	1605593,50	1609669,60	1609669,60	1609669,60
disp avr.	**tons**	34904,20652	36583,4	36583,4	34904,20652
fuel total	**tons**	13071,80	12591,95	12954,96	12437,77
fuel avr	**tons**	284,1695652	286,1806818	294,4308934	282,676539
mile total	**miles**	112189,00	104371,26	104371,26	104371,26
hours total	**hrs**	5815,596667	5769,75	5297,475044	5297,475044
speed avr	**knots**	19,70	19,52	19,70	19,70
cons per Nm	**tons**	0,116572129	0,120816085	0,124123822	0,119168515

Speed influences the consumption therefore consumption of the of “Post period” normalized corresponding to the average speed of “Pre- period”. That is performed by changing the below equation for the Fuel Oil Consumption (FOC) of Post period

$$FOC_{Normalized} = FOC_{\ Evaluation}\ x\ \left(\frac{Average\ \ Speed\ \ Reference\ \ Period}{Average\ \ Speed\ \ Evaluation\ Period}\right)^{3} \qquad (17)$$

Above stated equation transforms the main engine fuel oil consumption for data entry of post- period to a normalized value according the pre-period’s average speed.

Then data statistically examined. If the variation was significant between “*the average fuel consumption per mile*” value of “Pre-period” and corrected-normalized “*average fuel consumption per mile”* value of the “Post period”. Following equation is used to examine the difference among two means for the samples:

$$t = \frac{(\overline{X}_1 - \overline{X}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad (18)$$

Results to be displayed at the confidence level of 95%

4 DISCUSSING AND RESULTS

According to the Trim optimization software entries, all Test Vessels have achieved certain amount of fuel savings on their “Post -period(s) “as shown below figure 30 as percentage. Statistically compared actual “average fuel consumption per mile” results of the vessels belong to the “Pre-period” and “Post-period” correspondingly. These cycles can also be compared with saving potential of shown on the figure 30

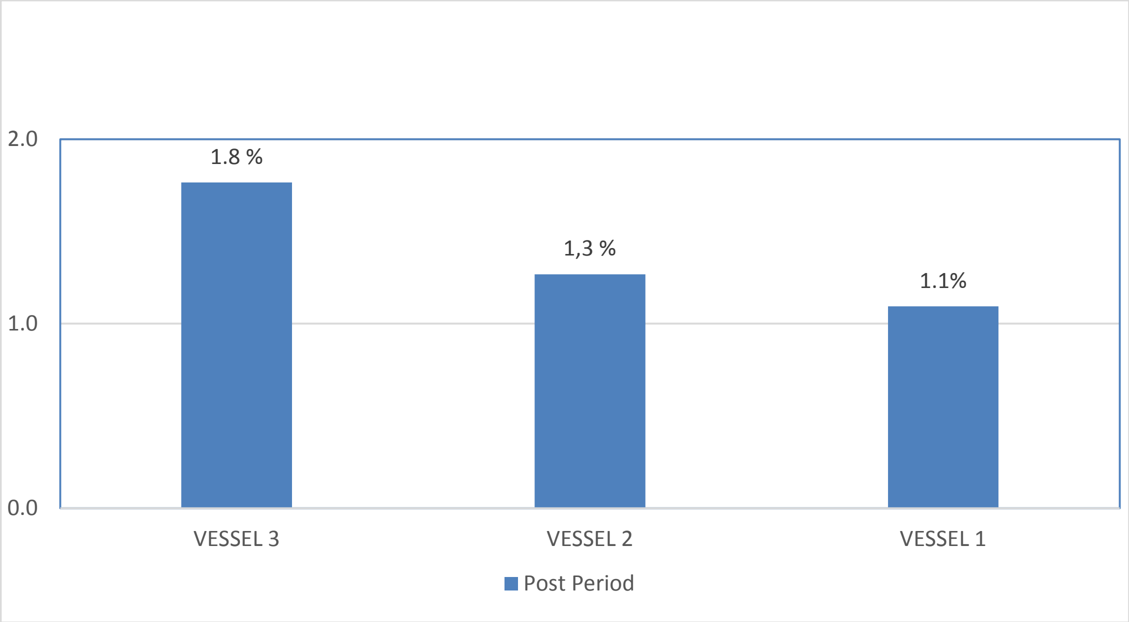

Figure 30 Fuel saving results according to Trim optimization Software

4.1 Results of Test Vessel 1

Vessel 1 was built in 2005. She entered dry-dock in March 3rd, 2015 and had a hull maintenance with fully blasted and coated with foul Release coating advance technology.

After this dry dock period vessel have completed in 44 round-trip voyages in the first year after out- docking which is so called as Pre-period in the analysis. In pre-period vessel could not be used for trim optimization method.

In December 29th, 2017 vessel had a dry dock and had a hull maintenance with full layer foul release coating.

In this period vessel has started to use Trim optimization methods with completed 46 round-trip voyages in the first year after last dry docking which is so called as "Post-period"

Table 8 Dry Dock history of Test Vessel 1

Vessel Name		DDn+1	DDn+2
VESSEL 1	Date of Drydock	29.03.2015	29.12.2017
	Shipyard	GEMAK	GEMAK
	Blasting	SA 2 %100	Spot %5
	Hull Coating	Foul Release Coating - Advanced	1 Full layer Foul Release
	Trim Optimization in use after DryDock	NO	YES
	Engine Overhaul	NO	NO

To determine the effect of the trim optimization methods, the fuel oil consumption per mile of the vessel 1 gathered at both "Pre-Period" and "Post-Period" have been compared with paired sample t-test and below results has obtained.

Table 9 Paired Samples Statistic of Test Result of Test Vessel 1

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	VAR00002	.116572	46	.0038310	.0005649
	VAR00003	.120674	46	.0060875	.0008975

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	VAR00002 & VAR00003	46	,092	,542

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	VAR00002 - VAR00003	-.0041023	.0068868	.0010154	-.0061475	-.0020572	-4,040	45	,000

According to paired sample t-test, A significant difference between "Pre-period" and "Post period" can be seen easily for the fuel consumptions of Pre and Post periods. However according to Trim optimization software results, fuel consumption of post-period should be 1,1 % lower than pre-period, but in reality, fuel consumption of post period was 2,23 %

higher than pre-period. Therefore, results did not confirm calculations of Trim Optimization Software and vessel consumed more fuel during post period.

4.1 Results of Test Vessel 2

Vessel 2 was also built in 2005 She has the same specification with the test vessel. She entered dry-dock in May 16Th 2015 and her hull fully blasted and coated with same technology applied on Test Vessel 1.

We have evaluated 47 round-trip voyages of the Test Vessel 2 in the first year after completion of her dry-docking period in 2015 which is called Pre-period in the analysis. In pre-period, trim optimization method is not used.

As the Post-period of the Vessel 2, 47 voyages evaluated in the first year after last dry docking held in January 18Th 2018. It is important that vessel has started to use Trim optimization just after this dry-dock.

Vessel Name		DDn+1	DDn+2
VESSEL 2	Date of Drydock	16.05.2015	15.01.2018
	Shipyard	BESIKTAS	GEMAK
	Blasting	SA 2 %100	Spot %5
	Hull Coating	Foul Release Coating - advanced	1 Full layer Foul Release
	Trim Optimization in use after DryDock	NO	YES
	Engine Overhaul	NO	NO

Table 10 Dry Docking History of the Test Vessel 3

Analysing fuel consumptions per mile of Test Vessel 2 on both “Pre-period” and “Post-period” via sample paired t-test show us below finding.

Table 11 Paired Samples Statistic of Test Result of Test Vessel 2

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	VAR00001	,1152	47	,00477	,00070
	VAR00002	,1203	47	,00745	,00109

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	VAR00001 & VAR00002	47	-,036	,810

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	VAR00001 - VAR00002	-,00504	,00899	,00131	-,00768	-,00240	-3,845	46	,000

As shown on the table 11, the statistical results confirmed that significant difference between exists for "Pre-period" and "Post-period" for the Vessel 2. however, "average fuel consumption per mile" of Post Period was higher than pre period and according to Trim Optimization software "Post period's fuel consumption needed to be %1,3 lower than "Pre period". The vessel consumed %4,49 higher fuel consumption in post period compared with pre period. Results didn't confirmed calculations of Trim Optimization software.

4.2 Results of Test Vessel 3

Vessel 3 was built at the same shipyard on the same year with Test Vessel 1 and Test Vessel 2. She entered dry dock on 2nd June 2015 and hull of vessel fully blasted and coated with foul release coating same as the other sample Test Vessels. After this dry dock period 47 round -trip voyages have been evaluated derived without Trim optimization method.

The Vessel 3 entered the dry dock again in February 19th of 2018 and bottom of the vessel coated with same technology applied on the last dry dock period of the Test Vessel 1 and Test Vessel 2. After this period Test Vessel 3 has started to use trim optimization method via Eco-Assistant Trim optimization tool and 42 of round-trip voyages have been considered at the first year of the dry docking held in 2018.

Table 12 Dry Docking History of the Test Vessel 3

Vessel Name		DDn+1	DDn+2
VESSEL 3	Date of Drydock	2.06.2015	19.02.2018
	Shipyard	BESIKTAS	GEMAK
	Blasting	SA 2 %100	Spot %5
	Hull Coating	Foul Release Coating - Advanced	1 Full layer Foul Release
	Trim Optimization in use after DryDock	NO	**YES**
	Engine Overhaul	NO	NO

To determine the effect of the trim optimization methods used on Test Vessel 3, "average the fuel oil consumptions per mile" of the Test Vessel 3 gathered at both Pre-Period and Periods have been compared with method of paired sample t-test via SPSS program and results shows us as below calculation as shown on the table 13;

Table 13 Paired Samples Statistic of Test Result of Test Vessel 3

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	VAR00002	,1167	42	,00615	,00095
	VAR00003	,1151	42	,00444	,00069

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	VAR00002 & VAR00003	42	,134	,397

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	VAR00002 - VAR00003	,00166	,00709	,00109	-,00055	,00387	1,516	41	,137

As differently, the paired samples result of the Vessel 3 shows us that existing of a significant difference between the “average fuel consumption per mile” values at “Pre-period” and “Post-period”

While Trim optimization software results the post -period should be 1,8 % lower than pre-period, the real fuel consumption of post period is 1,8 % as same with “Pre-period”. Therefore, it seems that fuel savings obtained by means of Trim optimization software is confirmed by the real field data results, but t-test results didn’t confirmed difference between pre and post period significantly.

5 CONCLUSION

Increasing fuel prices and environmental matters and also international regulations are forcing shipping owners /operators to find a way on how the fuel efficiency of vessels can be improved in order to reduce costs and GHG. Considering the fuel cost is by far the biggest part of the operating cost of a ship, a fractional savings in fuel consumption can result in considerable savings among the operational costs. Moreover, fuel savings have environmental benefits in the reduction of greenhouse gas emissions and CO2.

The trim optimization method is identified by the IMO as among the fuel-efficient operations can provide energy efficiency by reducing fuel consumption. [9]

A close relationship exists between fuel consumption and ship trim so that vessel owners and operators should strictly be able to decrease fuel consumption by means of optimizing trim of the vessel. Thus, they may be able to save 5% of fuel costs in annually. [20] however this results mainly outcomes from the calculations generated by CFD analysis in the literature.

But in actual life, it is very hard to measure the effect of the trim optimization due to operational factors influence the energy efficiency such as Hull resistance, Propulsion systems, wind, wave, cargo carried, speed and duration of the voyage.

In this thesis, three test vessels selected among the twelve sisters high-speed RO-RO vessels. All those three-vessel built in the same shipyard with the same arrangement as sister vessel and launched into the two months interval in 2005.

Dnv GL Eco assistant trim optimization software, which is based on CFD calculations and specially design for the test vessel, has been installed. Also, the dataset used in the study were obtained Navigator insight software used by the Test vessel.

To also eliminate the hull and propeller resistance, two periods of the test vessels analysed. The first period is the period so-called Pre-Period all the test vessels enter dry dock in the same month where fully hull coating applied with the same coating technology and polishing the propeller blades. In this period, all data monitored belongs to an interval as one year after dry docking. Test vessels did not use Trim optimization software in this interval. The second period is the period called Post-Period, in which all the test vessels had dry dock maintenance where fully hull coating applied with the same coating technology and polishing the propeller blades. Evaluate data belong to an interval as one year after dry-docking with usage of Eco Assistant Trim optimization software.

Actual fuel consumptions evaluated by ISO 19030 standards to minimize the controllable operational factors such as hull resistance, propulsion systems and ITTC formula applied in order to provide speed and displacements correction to data gathered.

At the test vessel 1 “average fuel consumption per mile” of 44 roundtrip at the pre-period and 46 “average fuel oil consumption per mile” of 46 voyages have been compared with paired sample t-test statistically and results did not match the outcome from trim optimization software. However according to Trim optimization software results, fuel consumption of post-period should be 1,1 % lower than pre-period, but in real field data, fuel consumption of post-period was 2,23 % higher than pre-period

At the test vessel 2, 47 of the voyage results have been included in the statistical test and compared with 47 samples in the Post-period of vessel 2. Trim Optimization software post period’s fuel consumption needed to be %1,3 lower than the pre-period. In reality, the vessel consumed %4,49 higher fuel consumption in the post-period compared pre-period. Results didn’t confirm the calculations of Trim Optimization software.

Vessel 3 is the only vessel in which statistically tested of the vessel average fuel consumption per mile significantly decreased in Post -period and confirmed as the fuel-saving results of trim optimization software. While Trim optimization software results in the post-period should be 1,8 % lower than the pre-period, the real fuel consumption of the post-period is 1,8 % the as same “Pre-period”. Therefore, it seems that fuel savings obtained by means of Trim optimization software is confirmed by the real field data results

As a conclusion, it has been clearly seen that observation of the effect of trim optimization is quite difficult on the real-life even if the operational factors of the energy efficiency are minimized or eliminated. The reason lying of this difficulty could be human error as the crew might not log and report the data correctly or might not adjust the trim of the vessel according to optimum trim value given by trim optimization software. Other possibility is that chief engineers could calculate the consumption the fuel wrongly.

Another reason could be the effect of uncontrollable operational factors such as wind and wave resistance, which are ignored in this study. Also, the usage of the rudder might be another factor that might affect the result of the study.

As future proposal to evaluating of the effect of the trim optimization precisely, an integrated sensor system (Consisting of draught gauges, wind wave and engine sensors, flow meters, or tank sensors) which is able to log and report the data automatically should be installed to the test vessels. Thus, human error on the reporting and error on trim adjusting can be avoided. And, data can be evaluated with other variables such as wind and sea states or on calculating remained fuel oil on board that can be provided.

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7 CURRICULUM VITAE

Name: Uğur

Surname: Demir

Address: Sancaktepe/ İSTANBUL / TURKEY

Mobile: 0532 612 60 99

E-mail: ugurddemir@gmail.com

Date of Birth: 18/12/1982

Civil status: Married

Military Service: Completed

EDUCATION

Suleyman Demirel Anatolian High School 1997 – 2001

Turkish Maritime Education Foundation Deck Department (TUDEV) 2001 -2005

Anatolian University Business Administration Faculty 2003-2007

Piri Reis University Gradute School of Science and Engineeering - Maritime Transportation and Management Engineering

Still Continue…

PROFESSIONAL EXPERIENCE

HR Business Partner & Crewing Superintendent

DFDS Denizcilik ve Taşımacılık.A.Ş

June 2018 - continue

Crewing Superintendent

“U.N Ro-Ro Isletmeleri A.S”.

January 2015 – June 2018

Master

“U.N Ro-Ro Isletmeleri A.S”.

July 2012 – January 2015

Chief Officer

“U.N Ro-Ro Isletmeleri A.S”.

May 2010 – July 2012

Deck Officer

“U.N Ro-Ro Isletmeleri A.S”.

May 2005 – May 2010

Deck Cadet

Karahasan Denizcilik.

July 2004 – November 2004

Deck Cadet

“UND Ro-Ro Isletmeleri A.S”.

May 2004 – July 2004

Deck Cadet

“UND Ro-Ro Isletmeleri A.S”.

November 2002 – March 2003

LANGUAGE

Advanced writing and speaking English

8 APPENDIX -A

Table A 1 Dataset of Test Vessel 1

													ISO AND LCV CORRECTED		ACC TO 18557,6 DISP		ACC TO 18557,6 DISP	ACC TO 18557,6 DISP
Ship	Year	Voyage	Ports	Round Trip Displacement	Round Trip Cons	Round trip duration	Round trip av. Cons per hour	Total Dist	Total Av speed	Av speed in m/s	Total av cons/mile	Av.Cons per engine	Av.cons per engine in kg	Brake Power for one engine	brake power for 2 engine	expected speed in knots	expected speed in m/s	speed loss	speed loss
Vessel 1	DDN +1	34	PEN - TOU - PEN	35745,4	309,6	144,5	2,142560554	2732	19,5523316	10,05771937	0,113323572	1,071280277	1071,280277	1008,558949	5301,534298	10603,0686	20,40879669	10,49828502	-4,196548716
Vessel 1	DDN +1	37	PEN - TOU - PEN	34711,4	300	141,6	2,118644068	2732	19,5523316	10,05771937	0,109809663	1,059322034	1059,322034	997,3008375	5235,299155	10470,59831	20,35027398	10,46818094	-3,92104001
Vessel 1	DDN +1	38	PEN - TOU - PEN	37323,1	308,3	145,8	2,114540466	2732	19,5523316	10,05771937	0,112847731	1,057270233	1057,270233	995,3691657	5223,911569	10447,82314	20,34013782	10,4629669	-3,873160722
Vessel 1	DDN +1	38	PEN - TOU - PEN	36827,9	311,5	142,9	2,179846046	2732	19,5523316	10,05771937	0,114019034	1,089923023	1089,923023	1026,1102	5404,338954	10808,67791	20,4981981	10,54427311	-4,614388566
Vessel 1	DDN +1	39	PEN - TRI - MER	35892,9	290,8	123,0666667	2,362946912	2535	19,80868768	10,18958894	0,114714004	1,181473456	1181,473456	1112,300537	5901,142673	11802,28535	20,907568	10,75485298	-5,255897395
Vessel 1	DDN +1	40	MER - TRI - MER	36012,8	310,1	139,9	2,216583274	2694	19,80868768	10,18958894	0,115107647	1,108291637	1108,291637	1043,403368	5505,089604	11010,17921	20,58417833	10,58850133	-3,767411233
Vessel 1	DDN +1	40	MER - TRI - MER	34840,8	305,7	133,6	2,288173653	2694	19,80868768	10,18958894	0,113474388	1,144086826	1144,086826	1077,10282	5699,877306	11399,75461	20,74603666	10,67176126	-4,518207474
Vessel 1	DDN +1	41	MER - TRI - MER	31050	313,4	138,2	2,267727931	2694	19,80868768	10,18958894	0,116332591	1,133863965	1133,863965	1067,478487	5644,455808	11288,91162	20,70055429	10,64836512	-4,30841897
Vessel 1	DDN +1	43	MER - TRI - MER	34588,8	319,5	134,3	2,379002234	2694	19,80868768	10,18958894	0,118596882	1,189501117	1189,501117	1119,858194	5944,067575	11888,13515	20,94130518	10,77220739	-5,408533485
Vessel 1	DDN +1	43	MER - TRI - PEN	34251	306	126,7	2,415153907	2531	19,9821871	10,27883705	0,12090083	1,207576953	1207,576953	1136,875727	6040,344936	12080,68987	21,01609752	10,81068056	-4,91961182

Vessel 1	DDN +1	44	PEN - TRI - PEN	34900,2	282	121,2	2,326732673	2372	19,9821871	10,27883705	0,118887015	1,163366337	1163,366337	1095,253553	5803,944159	11607,88832	20,83025806	10,71508475	-4,07134159
Vessel 1	DDN +1	46	PEN - TRI - PEN	33318	281,9	122,3	2,304987735	2372	19,9821871	10,27883705	0,118844857	1,152493868	1152,493868	1085,017646	5745,329709	11490,65942	20,7830089	10,69077978	-3,853252448
Vessel 1	DDN +1	47	PEN - TRI - PEN	34141,9	277,5	121,7	2,280197206	2372	19,9821871	10,27883705	0,116989882	1,140098603	1140,098603	1073,348099	5678,275669	11356,55134	20,72836181	10,66266931	-3,599776525
Vessel 1	DDN +1	47	PEN - TRI - PEN	34240,5	282,1	119,6	2,358695652	2372	19,86824053	10,22022293	0,118929174	1,179347826	1179,347826	1110,299359	5889,759449	11779,5189	20,89858009	10,7502296	-4,930189324
Vessel 1	DDN +1	48	PEN - TRI - PEN	34797	278,5	119	2,340336134	2372	19,86824053	10,22022293	0,117411467	1,170168067	1170,168067	1101,657056	5840,517	11681,034	20,85949831	10,73012593	-4,752069168
Vessel 1	DDN +1	49	PEN - TRI - PEN	36103,7	287,3	125,2	2,294728435	2372	19,86824053	10,22022293	0,121121417	1,147364217	1147,364217	1080,188326	5717,609827	11435,21965	20,76049574	10,67919901	-4,297851184
Vessel 1	DDN +1	50	PEN - TRI - PEN	34124,4	280,6	118,6133333	2,365669964	2372	19,86824053	10,22022293	0,118296796	1,182834982	1182,834982	1113,582348	5908,430162	11816,86032	20,91331292	10,75780817	-4,997163293
Vessel 1	DDN +1	50	PEN - TRI - PEN	33818	276,5	121,4	2,277594728	2372	19,86824053	10,22022293	0,116568297	1,138797364	1138,797364	1072,123045	5671,222205	11342,44441	20,72257597	10,65969308	-4,122728006
Vessel 1	DDN +1	51	PEN - TRI - PEN	33185,8	269,9	122,8	2,197882736	2372	19,89646276	10,23474044	0,113785835	1,098941368	1098,941368	1034,600539	5453,871254	10907,74251	20,54066726	10,56611924	-3,136239408
Vessel 1	DDN +1	52	PEN - TRI - PEN	30505,2	274,4	123,8833333	2,214987219	2372	19,89646276	10,23474044	0,115682968	1,10749361	1107,49361	1042,652063	5500,723662	11001,44732	20,58048518	10,58660158	-3,323645761
Vessel 1	DDN +1	53	PEN - TRI - PEN	34574,8	280,1	126	2,223015873	2372	19,89646276	10,23474044	0,118086003	1,111507937	1111,507937	1046,431359	5522,675419	11045,35084	20,59902454	10,59613822	-3,410655587
Vessel 1	DDN +1	54	PEN - TRI - PEN	34546,7	288,6	123,4	2,338735818	2372	19,89646276	10,23474044	0,121669477	1,169367909	1169,367909	1100,903746	5836,218389	11672,43678	20,85607105	10,72836295	-4,60109813
Vessel 1	DDN +1	55	PEN - TRI - PEN	34708,1	282,1	120,2	2,346921797	2372	19,85528192	10,21355702	0,118929174	1,173460899	1173,460899	1104,757099	5858,196007	11716,39201	20,87356722	10,73736298	-4,87834826
Vessel 1	DDN +1	57	PEN - TRI - PEN	34652,4	275,4	121,6	2,264802632	2372	19,85528192	10,21355702	0,116104553	1,132401316	1132,401316	1066,101473	5636,512669	11273,02534	20,69399908	10,64499313	-4,052948679
Vessel 1	DDN +1	58	PEN - TRI - PEN	33791,6	265,3	120,7	2,198011599	2372	19,85528192	10,21355702	0,111846543	1,0990058	1099,0058	1034,661198	5454,22467	10908,44934	20,54096889	10,5662744	-3,338143271
Vessel 1	DDN +1	58	PEN - TRI - PEN	36058	271,4	119,6	2,269230769	2372	19,85528192	10,21355702	0,114418212	1,134615385	1134,615385	1068,185912	5648,535177	11297,07035	20,70391727	10,65009504	-4,098911988
Vessel 1	DDN +1	59	PEN - TRI - PEN	34561	268,5	122,0333333	2,20021852	2372	19,85528192	10,21355702	0,113195616	1,10010926	1100,10926	1035,700053	5460,276285	10920,55257	20,54613077	10,56892967	-3,362427979
Vessel 1	DDN +1	59	PEN - TRI - PEN	34521,4	280,1	122,9	2,27908869	2372	19,5843792	10,07420466	0,118086003	1,139544345	1139,544345	1072,826292	5675,271601	11350,5432	20,7258985	10,66140219	-5,507695135
Vessel 1	DDN +1	60	PEN - TRI - PEN	36705,5	282	120	2,35	2372	19,5843792	10,07420466	0,118887015	1,175	1175	1106,206089	5866,453416	11732,90683	20,88012391	10,74073574	-6,205637087
Vessel 1	DDN +1	60	PEN - TRI - PEN	35053	286,4	124,1	2,307816277	2372	19,5843792	10,07420466	0,12074199	1,153908139	1153,908139	1086,349114	5752,964841	11505,92968	20,78919082	10,69395976	-5,795375296

Vessel 1	DDN +1	61	PEN - TRI - PEN	36229	287,5	126,4	2,274525316	2372	19,5843792	10,07420466	0,121205734	1,137262658	1137,262658	1070,678193	5662,899744	11325,79949	20,71573993	10,65617662	-5,461358082
Vessel 1	DDN +1	61	PEN - TRI - PEN	34945	274	121,8	2,249589491	2372	19,5288576	10,04564435	0,115514334	1,124794745	1124,794745	1058,940252	5595,149011	11190,29802	20,65971305	10,62735639	-5,473722934
Vessel 1	DDN +1	62	PEN - TRI - PEN	36333	277,5	121	2,29338843	2372	19,5288576	10,04564435	0,116989882	1,146694215	1146,694215	1079,557551	5713,986133	11427,97227	20,75754463	10,67768096	-5,91923107
Vessel 1	DDN +1	62	PEN - TRI - PEN	35025	279,3	119,7	2,333333333	2372	19,5288576	10,04564435	0,117748735	1,166666667	1166,666667	1098,360656	5821,699221	11643,39844	20,8444763	10,72239861	-6,311593954
Vessel 1	DDN +1	63	PEN - TRI - PEN	36724	291,3	123,9	2,351089588	2372	19,5288576	10,04564435	0,122807757	1,175544794	1175,544794	1106,718987	5869,375376	11738,75075	20,88244184	10,74192808	-6,481925123
Vessel 1	DDN +1	64	PEN - TRI - PEN	35657,2	274,7	123	2,233333333	2372	19,58327709	10,07363773	0,115809444	1,116666667	1116,666667	1051,288056	5550,84743	11101,69486	20,62270954	10,60832178	-5,040232205
Vessel 1	DDN +1	64	PEN - TRI - PEN	35923	278,6	122,3	2,278004906	2372	19,58327709	10,07363773	0,117453626	1,139002453	1139,002453	1072,316127	5672,334084	11344,66817	20,7234885	10,66016249	-5,502024496
Vessel 1	DDN +1	65	PEN - TRI - PEN	34049	274	142,8	1,918767507	2372	19,58327709	10,07363773	0,115514334	0,959383753	959,3837535	903,2137445	4672,833635	9345,667269	19,82120584	10,19602828	-1,200374748
Vessel 1	DDN +1	66	PEN - TRI - PEN	32361	266,5	124	2,149193548	2372	19,58327709	10,07363773	0,112352445	1,074596774	1074,596774	1011,681272	5319,863533	10639,72707	20,42486253	10,50654929	-4,120397097
Vessel 1	DDN +1	66	PEN - TRI - PEN	31872,9	243,3	127	1,915748031	2372	19,58327709	10,07363773	0,102571669	0,957874016	957,8740157	901,7923989	4664,214461	9328,428921	19,81261181	10,19160752	-1,1575189
Vessel 1	DDN +1	67	PEN - ANC - TRI - PEN	37115	290,7	122,5	2,373061224	2381	19,58434318	10,07418613	0,122091558	1,186530612	1186,530612	1117,061607	5928,1959	11856,3918	20,92885918	10,76580516	-6,424220182
Vessel 1	DDN +1	68	PEN - ANC - TRI - PEN	35229,4	263,8	124,2	2,123993559	2381	19,58434318	10,07418613	0,110793784	1,061996779	1061,996779	999,818982	5250,134028	10500,26806	20,36344557	10,4749564	-3,825985045
Vessel 1	DDN +1	69	PEN - TRI - PEN	35708	272,8	122,1	2,234234234	2372	19,58434318	10,07418613	0,115008432	1,117117117	1117,117117	1051,712134	5553,30534	11106,61068	20,62477026	10,60938182	-5,044551124
Vessel 1	DDN +1	69	PEN - TRI - ANC - PEN	36251	294,6	141	2,089361702	2381	19,26272263	9,90874452	0,123729525	1,044680851	1044,680851	983,5168668	5153,892898	10307,7858	20,27732399	10,43065546	-5,003625527
Vessel 1	DDN +1	70	PEN - TRI - PEN	36045	278	124,5	2,232931727	2372	19,26272263	9,90874452	0,117200675	1,116465863	1116,465863	1051,09901	5549,75163	11099,50326	20,62179052	10,60784904	-6,590445608
Vessel 1	DDN +1	70	PEN - TRI - PEN	36574,7	279,7	122,6	2,281402936	2372	19,26272263	9,90874452	0,117917369	1,140701468	1140,701468	1073,915668	5681,542629	11363,08526	20,7310392	10,66404657	-7,082696437
Vessel 1	DDN +2	71	PEN-BARI-TRI-PEN	35763,4	269,63	130,7	2,06296863	2385	19,7	10,13368	0,113052411	1,031484315	1031,484315	971,0929619	5080,22596	10160,45192	20,2103093	10,3961831	-2,524994991
Vessel 1	DDN +2	73	PEN-BARI-TRI-PEN	37946,8	266,9	127,3333333	2,096073298	2385	19,7	10,13368	0,111907757	1,048036649	1048,036649	986,6761897	5172,581639	10345,16328	20,29417278	10,43932248	-2,927799949
Vessel 1	DDN +2	74	PEN-BARI-TRI-PEN	38121,2	283,3	133,7666667	2,117866932	2395,3	19,7	10,13368	0,118273285	1,058933466	1058,933466	996,9350197	5233,143103	10466,28621	20,34835656	10,46719461	-3,186284635
Vessel 1	DDN +2	75	PEN-BARI-TRI-PEN	37754,2	280,84	129,5666667	2,167532802	2385,1	19,7	10,13368	0,117747684	1,083766401	1083,766401	1020,314035	5370,449835	10740,89967	20,46891661	10,5292107	-3,756508569

Vessel 1	DDN +2	75	PEN-BARI-TRI-PEN	37084,2	288,74	130,2	2,217665131	2369,6	19,24754304	9,900936138	0,121851789	1,108832565	1108,832565	1043,912626	5508,048402	11016,0968	20,5866795	10,58978794	-6,504868674
Vessel 1	DDN +2	76	PEN-BARI-TRI-PEN	36957,6	275,7	128,6666667	2,142746114	2387,5	19,24754304	9,900936138	0,11547644	1,071373057	1071,373057	1008,646297	5302,047303	10604,09461	20,4092471	10,49851671	-5,692047628
Vessel 1	DDN +2	77	PEN-BARI-TRI-MER	35288,4	283,88	134,5333333	2,110109019	2554,5	19,24754304	9,900936138	0,11112938	1,055054509	1055,054509	993,2831681	5211,60666	10423,21332	20,32916029	10,45732005	-5,320521035
Vessel 1	DDN +2	78	MER-TRI-PEN	36897,1	294,45	133,6	2,203967066	2529,7	19,24754304	9,900936138	0,116397201	1,101983533	1101,983533	1037,464591	5470,550753	10941,10151	20,55488155	10,57343107	-6,360233751
Vessel 1	DDN +2	79	PEN-AMB-TRI-PEN	37431	287,6	130,2166667	2,208626648	2373,9	19,28074325	9,91801433	0,121150849	1,104313324	1104,313324	1039,657977	5483,314484	10966,62897	20,56572958	10,5790113	-6,248192262
Vessel 1	DDN +2	79	PEN-AMB-TRI-PEN	37505,2	280,8	129,35	2,170854271	2375,7	19,28074325	9,91801433	0,118196742	1,085427136	1085,427136	1021,877538	5379,597304	10759,19461	20,47683854	10,53328574	-5,841210692
Vessel 1	DDN +2	80	PEN-AMB-TRI-PEN	36963,1	293,11	132,1333333	2,218289606	2374,3	19,28074325	9,91801433	0,123451122	1,109144803	1109,144803	1044,206583	5509,756084	11019,51217	20,58812246	10,59053019	-6,350162354
Vessel 1	DDN +2	81	PEN-AMB-TRI-PEN	38719,4	287,2	128,9833333	2,226644269	2377,5	19,28074325	9,91801433	0,120799159	1,113322135	1113,322135	1048,13934	5532,58766	11065,17532	20,60737179	10,60043205	-6,437640591
Vessel 1	DDN +2	82	PEN-AMB-TRI-PEN	37776,1	290,4	127,3333333	2,280628272	2346,957143	19,34228823	9,949673067	0,123734684	1,140314136	1140,314136	1073,551013	5679,443721	11358,88744	20,72931925	10,66316182	-6,691155632
Vessel 1	DDN +2	1	PEN-AMB-TRI-PEN	37921,4	290,82	129,9333333	2,238224731	2327,514286	19,34228823	9,949673067	0,12494875	1,119112365	1119,112365	1053,590564	5564,188642	11128,37728	20,63388396	10,61406991	-6,25958605
Vessel 1	DDN +2	2	PEN-AMB-TRI-PEN	37012,9	283,36	127,35	2,225049077	2308,071429	19,34228823	9,949673067	0,122769164	1,112524539	1112,524539	1047,388442	5528,230479	11056,46096	20,60370438	10,59854553	-6,122278426
Vessel 1	DDN +2	3	PEN-AMB-TRI-PEN	34885,2	281,23	125,2	2,246246006	2288,628571	19,34228823	9,949673067	0,122881451	1,123123003	1123,123003	1057,366387	5586,045895	11172,09179	20,65213352	10,62345748	-6,342421155
Vessel 1	DDN +2	4	PEN-AMB-TRI-PEN	36349,9	281,3	128,4	2,190809969	2269,185714	19,39049855	9,974472455	0,123965173	1,095404984	1095,404984	1031,271203	5434,463507	10868,92701	20,52407313	10,55758322	-5,52314626
Vessel 1	DDN +2	4	PEN-AMB-TRI-PEN	37994,9	279,9	129,5	2,161389961	2249,742857	19,39049855	9,974472455	0,124414219	1,080694981	1080,694981	1017,422441	5353,520598	10707,0412	20,45421982	10,52165067	-5,200497859
Vessel 1	DDN +2	5	PEN-AMB-TRI-PEN	36651,8	283,44	128,4333333	2,206903711	2230,3	19,39049855	9,974472455	0,127086042	1,103451856	1103,451856	1038,846946	5478,59595	10957,1919	20,56172219	10,5769499	-5,696135902
Vessel 1	DDN +2	5	PEN-AMB-TRI-PEN	37449,5	291,02	129,2666667	2,251315111	2210,857143	19,39049855	9,974472455	0,131632205	1,125657555	1125,657555	1059,752546	5599,845514	11199,69103	20,66361868	10,62936545	-6,161167347
Vessel 1	DDN +2	6	PEN-AMB-TRI-PEN	36631,8	285,23	128,6666667	2,216813472	2191,414286	19,39049855	9,974472455	0,130157954	1,108406736	1108,406736	1043,511728	5505,719217	11011,43843	20,58471067	10,58877517	-5,80145205
Vessel 1	DDN +2	6	PEN-AMB-TRI-PEN	36912,7	284,79	129,1333333	2,205394941	2171,971429	19,50692588	10,03436267	0,131120509	1,10269747	1102,69747	1038,136728	5474,46297	10948,92594	20,55820927	10,57514285	-5,113691483
Vessel 1	DDN +2	7	PEN-AMB-TRI-PEN	37132,6	291,36	130,1	2,239508071	2152,528571	19,50692588	10,03436267	0,135357088	1,119754035	1119,754035	1054,194666	5567,687352	11135,3747	20,63680999	10,61557506	-5,475090955
Vessel 1	DDN +2	10	PEN-AMB-TRI-PEN	36853,4	282,46	128,5833333	2,196707712	2133,085714	19,50692588	10,03436267	0,132418495	1,098353856	1098,353856	1034,047424	5450,648358	10901,29672	20,53791569	10,56470383	-5,019934016

Vessel 1	DDN +2	11	PEN-AMB-TRI-PEN	37720,2	313,13	134,3166667	2,331281797	2439,3	19,50692588	10,03436267	0,128368794	1,165640898	1165,640898	1097,394944	5816,18267	11632,36534	20,8400633	10,72012856	-6,396993176
Vessel 1	DDN +2	12	PEN-AMB-TRI-PAT-PEN	37776,2	295,41	135,2166667	2,184715888	2442,9	19,59667061	10,08052736	0,120925949	1,092357944	1092,357944	1028,402561	5417,725285	10835,45057	20,50971385	10,5501968	-4,451760019
Vessel 1	DDN +2	13	PEN-AMB-TRI-PAT-PEN	37199,3	304,25	132,1333333	2,302598385	2444,7	19,59667061	10,08052736	0,124452898	1,151299193	1151,299193	1083,892917	5738,877611	11477,75522	20,77777844	10,68808923	-5,684476001
Vessel 1	DDN +2	14	PEN-AMB-TRI-PAT-PEN	36310,9	276,88	128,1	2,161436378	2381,4	19,59667061	10,08052736	0,116267742	1,080718189	1080,718189	1017,44429	5353,648575	10707,29715	20,45433109	10,52170791	-4,193050748
Vessel 1	DDN +2	15	PEN-AMB-TRI-PAT-PEN	37734,8	291,3	131,1333333	2,221403152	2378,5	19,59667061	10,08052736	0,122472146	1,110701576	1110,701576	1045,67221	5518,268019	11036,53604	20,59530819	10,59422653	-4,848859607
Vessel 1	DDN +2	18	PEN-AMB-TRI-PAT-PEN	33870,2	264,95	125,6333333	2,108914832	2383,8	19,82551297	10,19824387	0,111146069	1,054457416	1054,457416	992,7210331	5208,289391	10416,57878	20,32619643	10,45579544	-2,463242217
Vessel 1	DDN +2	19	PEN-AMB-TRI-PAT-PEN	29750,8	257,9	126,8	2,033911672	2408,6	19,82551297	10,19824387	0,107074649	1,016955836	1016,955836	957,4150962	4998,802409	9997,604817	20,13509833	10,35749458	-1,537540819
Vessel 1	DDN +2	20	PEN-AMB-TRI-PEN	37907,4	270,95	145,2166667	1,865832664	2377,1	19,82551297	10,19824387	0,113983425	0,932916332	932,9163319	878,2959378	4521,202768	9042,405537	19,66765184	10,11704011	0,802643531
Vessel 1	DDN +2	21	PEN-AMB-TRI-PEN	35266,1	277,56	125,4	2,213397129	2370,7	19,82551297	10,19824387	0,117079344	1,106698565	1106,698565	1041,903567	5496,373025	10992,74605	20,57680207	10,58470698	-3,651146032
Vessel 1	DDN +2	22	PEN-AMB-TRI-PEN	36764	287,26	125,6	2,287101911	2372,8	19,72153193	10,14475603	0,121063722	1,143550955	1143,550955	1076,598323	5696,976314	11393,95263	20,74366691	10,67054226	-4,9274556
Vessel 1	DDN +2	22	PEN-TRI-PEN	36127,7	283,97	125,45	2,263611	2385,4	19,72153193	10,14475603	0,119045024	1,1318055	1131,8055	1065,540541	5633,276024	11266,55205	20,69132534	10,64361775	-4,686956442
Vessel 1	DDN +2	23	PEN-TRI-PAT-PEN	35873,2	297,45	128,6	2,312986003	2429,1	19,72153193	10,14475603	0,12245276	1,156493002	1156,493002	1088,782638	5766,911324	11533,82265	20,8004617	10,6997575	-5,187047178
Vessel 1	DDN +2	24	PEN-TRI-PAT-PEN	36633,8	288,87	130,3333333	2,216393862	2436,6	19,55722452	10,0602363	0,118554543	1,108196931	1108,196931	1043,314207	5504,571529	11009,14306	20,58374024	10,58827598	-4,987022296
Vessel 1	DDN +2	24	PEN-TRI-PAT-PEN	35743,6	285,02	131,4	2,169101979	2438,9	19,55722452	10,0602363	0,11686416	1,084550989	1084,550989	1021,052688	5374,771964	10749,54393	20,47266136	10,531137	-4,471508688
Vessel 1	DDN +2	25	PEN-TRI-PAT-PEN	36413,6	290,36	129,4666667	2,242739444	2437,8	19,55722452	10,0602363	0,119107392	1,121369722	1121,369722	1055,715757	5576,493985	11152,98797	20,64416702	10,61935951	-5,265131271
Vessel 1	DDN +2	25	PEN-TRI-PAT-PEN	37261,8	294,17	130,5333333	2,253600613	2440,4	19,55722452	10,0602363	0,120541714	1,126800306	1126,800306	1060,828392	5606,063983	11212,12797	20,66878494	10,63202298	-5,377966938
Vessel 1	DDN +2	27	PEN-TRI-PAT-PEN	34268,5	304,04	134,8666667	2,254374691	2437,2	19,55722452	10,0602363	0,124749713	1,127187346	1127,187346	1061,19277	5608,169647	11216,33929	20,67053302	10,63292219	-5,385968976
Vessel 1	DDN +2	28	PEN-TRI-PAT-PEN	37606,3	296,43	132,1	2,243981832	2436	19,74147315	10,15501379	0,121687192	1,121990916	1121,990916	1056,300581	5579,878823	11159,75765	20,64699161	10,62081248	-4,385716219
Vessel 1	DDN +2	29	PEN-TRI-PAT-PEN	35470	270,18	158,6	1,703530895	2434,9	19,74147315	10,15501379	0,110961436	0,851765448	851,7654477	801,8962763	4049,325836	8098,651671	19,15455315	9,853102139	3,064127854
Vessel 1	DDN +2	30	PEN-MARSEILLES-PEN	33967,4	324,41	147,9	2,193441515	2721,8	19,53189337	10,04720595	0,119189507	1,096720757	1096,720757	1032,50994	5441,686827	10883,37365	20,53025617	10,56076377	-4,86288525

Table A 2 Speed and Displacement Corrections calculation of Test Vessel 1

	Unit	Pre-Period	Post- Period	SPEED CORRECTION TO POST-PERIOD	DISPLACEMENT CORRECTION TO POST-PERIOD
Sample Size	**pcs**	46	44	44	44
disp total	**tons**	1605593,50	1609669,60	1609669,60	1609669,60
disp avr.	**tons**	34904,20652	36583,4	36583,4	34904,20652
fuel total	**tons**	13071,80	12591,95	12954,96	12437,77
fuel avr	**tons**	284,1695652	286,1806818	294,4308934	282,676539
mile total	**miles**	112189,00	104371,26	104371,26	104371,26
hours total	**hrs**	5815,596667	5769,75	5297,475044	5297,475044
speed avr	**knots**	19,70	19,52	19,70	19,70
cons per Nm	**tons**	0,116572129	0,120816085	0,124123822	0,119168515

Analysis 1	Speed loss	
	Pre-Period	-4,60344824
	Post-Period	-4,760340417
	Performance	-0,16%

Analysis 2	Fuel Consumption changes for the same period of anaylsis 1	
	Pre-Period	0,116572129
	Speed and Displacement Corrected Post- period	0,119168515
	Performance	2,23%

Table A 3 Dataset of Test Vessel 2

															ISO AND LCV CORRECTED		ACC TO 18557,6 DISP		ACC TO 18557,6 DISP
Ship	Year	Voyage	Ports	Round Trip Displacement	Round Trip Cons	Round trip duration	Round trip av. Cons per hour	Total Dist	Total Av speed	Av speed in m/s	Total av cons/mile	Av.Cons per engine	Av.cons per engine in kg	LCV corrected	Brake Power for one engine	brake power for 2 engine	expected speed in knots	expected speed in m/s	speed loss
Vessel 2	DDN+1	16	PEN - TOU - PEN	33575,6	306,9	147,3	2,083503055	2732	19,75080366	10,1598134	0,112335286	1,041751527	1041,751527	980,7590493	5137,564545	10275,12909	20,26255311	10,42305732	-2,525592176
Vessel 2	DDN+1	17	PEN - TOU - PEN	35735,3	316,4	138,8	2,279538905	2732	19,75080366	10,1598134	0,115812592	1,139769452	1139,769452	1073,03822	5676,491738	11352,98348	20,72689916	10,66191693	-4,709317553
Vessel 2	DDN+1	18	PEN - TOU - PEN	35084	304	143,6	2,116991643	2732	19,84567071	10,20861301	0,111273792	1,058495822	1058,495822	996,5229984	5230,714448	10461,4289	20,34619576	10,4660831	-2,460042433
Vessel 2	DDN+1	19	PEN - TOU - PEN	36135,1	310,1	143,7	2,157967989	2732	19,84567071	10,20861301	0,113506589	1,078983994	1078,983994	1015,811629	5344,083354	10688,16671	20,44600687	10,51742593	-2,93620246
Vessel 2	DDN+1	20	PEN - TOU - PEN	36413,4	311,6	143,4	2,172942817	2732	19,84567071	10,20861301	0,114055637	1,086471409	1086,471409	1022,86067	5385,346995	10770,69399	20,48181102	10,53584359	-3,105879193
Vessel 2	DDN+1	21	PEN - TOU - PEN	35741,5	308,1	142,4	2,163623596	2732	19,84567071	10,20861301	0,112774524	1,081811798	1081,811798	1018,47387	5359,678078	10719,35616	20,45957068	10,52440316	-3,000551593
Vessel 2	DDN+1	22	PEN - TOU - PEN	35380,9	307	144,6	2,123098202	2732	19,82369358	10,19730798	0,112371889	1,061549101	1061,549101	999,3975143	5247,651876	10495,30375	20,36124431	10,47382407	-2,640068169
Vessel 2	DDN+1	23	PEN - TOU - PEN	34938,1	305	142	2,147887324	2732	19,82369358	10,19730798	0,111639824	1,073943662	1073,943662	1011,066398	5316,255375	10632,51075	20,42170431	10,5049247	-2,928309611
Vessel 2	DDN+1	24	PEN - TOU - PEN	35324,5	310,1	141,5	2,191519435	2732	19,82369358	10,19730798	0,113506589	1,095759717	1095,759717	1031,605167	5436,411189	10872,82238	20,52574112	10,55844123	-3,420327379
Vessel 2	DDN+1	25	PEN - TOU - PEN	33998,5	300,5	146,3	2,053998633	2732	19,82369358	10,19730798	0,109992679	1,026999316	1026,999316	966,8705509	5055,126122	10110,25224	20,18725386	10,38432339	-1,800939771
Vessel 2	DDN+1	26	PEN - TOU - PEN	34362,9	301,2	148,6	2,0269179	2732	19,82369358	10,19730798	0,110248902	1,01345895	1013,45895	954,1229461	4979,154147	9958,308293	20,11676576	10,34806431	-1,456855349
Vessel 2	DDN+1	27	PEN - TOU - PEN	32514,1	294,5	147	2,003401361	2732	20,04324948	10,31024753	0,107796486	1,00170068	1001,70068	943,0530995	4912,943827	9825,887654	20,05445197	10,3160101	-0,055860379

Vessel 2	DDN+1	28	PEN - TOU - PEN	33915,1	303,8	144,4	2,103878116	2732	20,04324948	10,31024753	0,111200586	1,051939058	1051,939058	990,3501203	5194,29191	10388,58382	20,31366936	10,44935152	-1,331221231
Vessel 2	DDN+1	29	PEN - TOU - PEN	35180,6	315,4	145,5	2,167697594	2732	20,04324948	10,31024753	0,115446559	1,083848797	1083,848797	1020,391608	5370,903785	10741,80757	20,46931006	10,52941309	-2,081460362
Vessel 2	DDN+1	30	PEN - TRI - PEN	30740,9	262,8	117,2	2,242320819	2372	20,04324948	10,31024753	0,11079258	1,12116041	1121,16041	1055,518699	5575,35332	11150,70664	20,64321477	10,61886968	-2,906355871
Vessel 2	DDN+1	31	PEN - TRI - PEN	35178	272,5	119,9166667	2,272411397	2372	19,82992645	10,20051417	0,114881956	1,136205698	1136,205698	1069,683117	5657,165837	11314,33167	20,71102428	10,65375089	-4,254245539
Vessel 2	DDN+1	32	PEN - TOU - PEN	36732	311,2	145,9	2,132967786	2732	19,82992645	10,20051417	0,113909224	1,066483893	1066,483893	1004,043384	5274,995158	10549,99032	20,38543604	10,4862683	-2,725031677
Vessel 2	DDN+1	33	PEN - TOU - PEN	35727,3	315,5	138,8	2,273054755	2732	19,82992645	10,20051417	0,115483163	1,136527378	1136,527378	1069,985962	5658,911104	11317,82221	20,71246012	10,65448948	-4,260882882
Vessel 2	DDN+1	34	PEN - TOU - PEN	35997,3	324,7	142,6	2,276998597	2732	19,82992645	10,20051417	0,118850659	1,138499299	1138,499299	1071,842431	5669,606139	11339,21228	20,72124932	10,65901065	-4,301491955
Vessel 2	DDN+1	35	PEN - TOU - PEN	35156,1	309,5	143,2	2,161312849	2732	19,66595885	10,11616923	0,113286969	1,080656425	1080,656425	1017,386142	5353,307986	10706,61597	20,45403495	10,52155558	-3,852912654
Vessel 2	DDN+1	36	PEN - TOU - PEN	35907,6	315,2	143,8	2,191933241	2732	19,66595885	10,11616923	0,115373353	1,09596662	1095,96662	1031,799956	5437,547109	10875,09422	20,52671365	10,5589415	-4,193339545
Vessel 2	DDN+1	37	PEN - TOU - PEN	36268	311,5	142,6	2,184431978	2732	19,66595885	10,11616923	0,114019034	1,092215989	1092,215989	1028,268917	5416,945125	10833,89025	20,50904349	10,54985197	-4,110794558
Vessel 2	DDN+1	38	PEN - TOU - PEN	36072	335,6	142	2,363380282	2732	19,66595885	10,11616923	0,12284041	1,181690141	1181,690141	1112,504535	5902,302664	11804,60533	20,90848293	10,75532362	-5,942679271
Vessel 2	DDN+1	39	PEN - TOU - PEN	36098	324,2	166,1	1,951836243	2732	19,66595885	10,11616923	0,118667643	0,975918122	975,9181216	918,7800583	4766,99124	9533,98248	19,91406959	10,2437974	-1,24590678
Vessel 2	DDN+1	40	PEN - TRI - PEN	36200	277,4	120,5	2,302074689	2372	19,78236829	10,17605025	0,116947723	1,151037344	1151,037344	1083,646399	5737,463138	11474,92628	20,77663099	10,68749898	-4,785485685
Vessel 2	DDN+1	41	PEN - TRI - PEN	34832	268,7	120,4	2,231727575	2372	19,78236829	10,17605025	0,113279933	1,115863787	1115,863787	1050,532184	5546,466567	11092,93133	20,61903357	10,60643087	-4,057732753
Vessel 2	DDN+1	42	PEN - TOU - PEN	30692	303,6	141,9	2,139534884	2732	19,78236829	10,17605025	0,111127379	1,069767442	1069,767442	1007,134688	5293,167508	10586,33502	20,40144461	10,4945031	-3,034472929
Vessel 2	DDN+1	43	PEN - TOU - PEN	32686	307,9	142,1	2,166783955	2732	19,78236829	10,17605025	0,112701318	1,083391977	1083,391977	1019,961534	5368,386872	10736,77374	20,46712817	10,52829073	-3,345656842

Vessel 2	DDN+1	44	PEN - TOU - PEN	31497	296,8	145,6	2,038461538	2732	19,86509403	10,21860437	0,10863836	1,019230769	1019,230769	959,5568366	5011,574304	10023,14861	20,14697639	10,36360466	-1,399129824
Vessel 2	DDN+1	45	PEN - TOU - PEN	31610	302,3	144,6	2,090594744	2732	19,86509403	10,21860437	0,110651537	1,045297372	1045,297372	984,0972917	5157,327706	10314,65541	20,28042521	10,43225073	-2,047941153
Vessel 2	DDN+1	46	PEN - TOU - PEN	33365	307,2	148,8	2,064516129	2732	19,86509403	10,21860437	0,112445095	1,032258065	1032,258065	971,8214097	5084,552923	10169,10585	20,21427231	10,39822168	-1,727384849
Vessel 2	DDN+1	47	PEN - ANC - TRI - PEN	37060	261,2	117,4	2,224872232	2381	19,86509403	10,21860437	0,109701806	1,112436116	1112,436116	1047,305196	5527,747372	11055,49474	20,60329758	10,59833627	-3,582938794
Vessel 2	DDN+1	2	PEN - TRI - PEN	34364	292,3	132,8	2,201054217	2372	19,51282273	10,03739601	0,123229342	1,100527108	1100,527108	1036,093437	5462,56735	10925,1347	20,5480835	10,56993415	-5,038235149
Vessel 2	DDN+1	3	PEN - TRI - PEN	36386,6	289,9	145,5	1,992439863	2372	19,51282273	10,03739601	0,122217538	0,996219931	996,2199313	937,8932374	4882,006593	9764,013186	20,02504698	10,30088417	-2,557917842
Vessel 2	DDN+1	4	PEN - ANC - TRI - PEN	36789	280,2	117,3	2,388746803	2381	19,51282273	10,03739601	0,117681646	1,194373402	1194,373402	1124,445216	5970,070151	11940,1403	20,96162383	10,7826593	-6,911683494
Vessel 2	DDN+1	5	PEN - ANC - TRI - MER	35319	305,8	127,7	2,39467502	2544	19,51282273	10,03739601	0,120204403	1,19733751	1197,33751	1127,235782	5985,870576	11971,74115	20,97392724	10,78898817	-6,96628958
Vessel 2	DDN+1	6	MER - TRI - PEN	36665	310,1	126,2	2,457210777	2531	19,83507824	10,20316425	0,122520743	1,228605388	1228,605388	1156,672988	6151,692777	12303,38555	21,10112473	10,85441856	-5,999900517
Vessel 2	DDN+1	7	PEN - ANC - TRI - PEN	37026	311,7	124,9	2,495596477	2381	19,83507824	10,20316425	0,130911382	1,247798239	1247,798239	1174,742136	6252,705207	12505,41041	21,17693867	10,89341725	-6,336423099
Vessel 2	DDN+1	8	PEN - TRI - MER	35732	293,9	129,1333333	2,275942179	2535	19,83507824	10,20316425	0,115936884	1,137971089	1137,971089	1071,345147	5666,741917	11333,48383	20,71889713	10,65780068	-4,265762221
Vessel 2	DDN+1	9	MER - TRI - MER	32380	298,7	137	2,180291971	2694	19,83507824	10,20316425	0,110876021	1,090145985	1090,145985	1026,320108	5405,565115	10811,13023	20,49925411	10,54481631	-3,240000179
Vessel 2	DDN+1	10	MER - TRI - MER	33848	320,3	132,2	2,422844175	2694	19,96185837	10,26837995	0,118893838	1,211422088	1211,422088	1140,495736	6060,758044	12121,51609	21,03180205	10,81875898	-5,087265839
Vessel 2	DDN+1	11	MER - TRI - MER	32247,5	310,8	136,8	2,271929825	2694	19,96185837	10,26837995	0,115367483	1,135964912	1135,964912	1069,456428	5655,859346	11311,71869	20,70994913	10,65319783	-3,612228859
Vessel 2	DDN+1	12	MER - TRI - PEN	36128,2	317,9	130,5	2,436015326	2531	19,96185837	10,26837995	0,125602529	1,218007663	1218,007663	1146,695739	6095,664852	12191,3297	21,05853494	10,83251037	-5,207753397
Vessel 2	DDN+1	13	PEN - TRI - PEN	33118,5	279,4	119,3	2,341994971	2372	19,96185837	10,26837995	0,117790894	1,170997485	1170,997485	1102,437914	5844,971724	11689,94345	20,86304738	10,73195157	-4,319546393

Vessel 2	DDN+ 1	14	PEN - TRI - PEN	32388,9	270	119,8	2,25375626	2372	19,51885785	10,04050048	0,113827993	1,12687813	1126,87813	1060,901659	5606,487398	11212,9748	20,66913651	10,63220382	-5,5651994
Vessel 2	DDN+ 1	15	PEN - TRI - PEN	32281,2	270,5	125,2	2,160543131	2372	19,51885785	10,04050048	0,114038786	1,080271565	1080,271565	1017,023816	5351,185612	10702,37122	20,4521891	10,52060607	-4,563478494
Vessel 2	DDN+ 1	16	PEN - ANC - TRI - PEN	37687	286,9	118,6	2,419055649	2381	19,51885785	10,04050048	0,12049559	1,209527825	1209,527825	1138,712378	6050,704699	12101,4094	21,02407428	10,81478381	-7,159489691
Vessel 2	DDN+ 2	1	PEN-AMB-TRI-PEN	36104,1	290,7	133,9	2,171023152	2414,1	19,25845932	9,906551476	0,120417547	1,085511576	1085,511576	1021,957034	5380,06229	10760,12458	20,47724087	10,5334927	-5,951883609
Vessel 2	DDN+ 2	2	PEN-AMB-TRI-PEN	37055,7	275,4	130,1333333	2,116290984	2387,6	19,25845932	9,906551476	0,115345954	1,058145492	1058,145492	996,1931796	5228,770115	10457,54023	20,34446514	10,46519287	-5,338089809
Vessel 2	DDN+ 2	3	PEN-AMB-TRI-PEN	38917,8	298,35	130,4166667	2,287667732	2382,7	19,28824111	9,921871229	0,125215092	1,143833866	1143,833866	1076,86467	5698,507936	11397,01587	20,7449182	10,67118592	-7,021850247
Vessel 2	DDN+ 2	4	PEN-AMB-TRI-PEN	37093,9	291,09	134,25	2,168268156	2382,7	19,28824111	9,921871229	0,122168129	1,084134078	1084,134078	1020,660186	5372,475413	10744,95083	20,47067197	10,53011366	-5,776219055
Vessel 2	DDN+ 2	5	PEN-AMB-TRI-PEN	36990,3	276,92	130,7666667	2,117665052	2384,6	19,28824111	9,921871229	0,116128491	1,058832526	1058,832526	996,8399895	5232,582975	10465,16595	20,3478583	10,46693831	-5,2075121
Vessel 2	DDN+ 2	6	PEN-AMB-TRI-MER	36959,4	291,07	164,3333333	1,771217039	2547,6	19,28824111	9,921871229	0,11425263	0,885608519	885,6085193	833,7579034	4247,393999	8494,787997	19,37684888	9,967451064	-0,457286774
Vessel 2	DDN+ 2	7	MER-TRI-MER	37325	337,64	135,3166667	2,495184136	2694,7	19,38772311	9,973044766	0,125297807	1,247592068	1247,592068	1174,548036	6251,623249	12503,2465	21,17613313	10,89300288	-8,445404125
Vessel 2	DDN+ 2	8	MER-TRI-PEN	35706,4	316,98	127,55	2,485143081	2690,9	19,38772311	9,973044766	0,11779702	1,242571541	1242,571541	1169,82145	6225,2552	12450,5104	21,1564582	10,8828821	-8,360260873
Vessel 2	DDN+ 2	9	PEN-BARI-TRI-MER	37662	299,16	150,0833333	1,993292615	2539,5	19,38772311	9,973044766	0,117802717	0,996646308	996,6463076	938,2946503	4884,415082	9768,830165	20,02734287	10,30206517	-3,193732508
Vessel 2	DDN+ 2	10	MER-TRI-MER	36860,3	342,84	137,5833333	2,491871593	2550,4	19,38772311	9,973044766	0,134425972	1,245935796	1245,935796	1172,988736	6242,928877	12485,85775	21,16965487	10,88967047	-8,417386952
Vessel 2	DDN+ 2	11	MER-TRI-MER	33896,7	314,64	138,1833333	2,276975033	2695,4	19,44825044	10,00418002	0,11673221	1,138487517	1138,487517	1071,831339	5669,542255	11339,08451	20,72119687	10,65898367	-6,143209029
Vessel 2	DDN+ 2	12	MER-TRI-PEN	37405,9	359,05	159,95	2,244763989	2697,1	19,44825044	10,00418002	0,133124467	1,122381994	1122,381994	1056,668763	5582,009463	11164,01893	20,64876871	10,62172662	-5,813994486
Vessel 2	DDN+ 2	13	PEN-AMB-TRI-PEN	37399,4	274,74	131,7166667	2,08584082	2535	19,44825044	10,00418002	0,108378698	1,04292041	1042,92041	981,859496	5144,081658	10288,16332	20,26845421	10,42609285	-4,046701191

Vessel 2	DDN+2	14	PEN-AMB-TRI-PEN	36853,1	281,26	127,2666667	2,210005238	2378,1	19,44825044	10,00418002	0,118270889	1,105002619	1105,002619	1040,306915	5487,08912	10974,17824	20,56893284	10,58065905	-5,448422709
Vessel 2	DDN+2	15	PEN-AMB-TRI-MER	37276,6	314,58	134,9166667	2,331661519	2380	19,44825044	10,00418002	0,132176471	1,16583076	1165,83076	1097,573689	5817,203866	11634,40773	20,84088053	10,72054895	-6,682203726
Vessel 2	DDN+2	16	MER-TRI-MER	35008,4	326,29	137,6833333	2,369858371	2548,8	19,82107692	10,19596197	0,128017106	1,184929185	1184,929185	1115,55394	5919,633491	11839,26698	20,922131	10,76234419	-5,262628728
Vessel 2	DDN+2	17	MER-TRI-MER	35137,3	321,06	141,9	2,262579281	2709,1	19,82107692	10,19596197	0,118511683	1,131289641	1131,289641	1065,054884	5630,473266	11260,94653	20,68900878	10,64242612	-4,195135053
Vessel 2	DDN+2	18	MER-TRI-MER	34435,4	311,9	137,95	2,260964117	2697,6	19,82107692	10,19596197	0,115621293	1,130482059	1130,482059	1064,294585	5626,084676	11252,16935	20,68537917	10,64055905	-4,178324428
Vessel 2	DDN+2	19	MER-TRI-MER	34940,1	311,6	143,05	2,17825935	2708,6	19,82107692	10,19596197	0,115040981	1,089129675	1089,129675	1025,363301	5399,975364	10799,95073	20,49443811	10,54233896	-3,285580139
Vessel 2	DDN+2	20	MER-TRI-MER	34002,1	320,35	141,7833333	2,259433408	2697,4	19,98869379	10,28218409	0,118762512	1,129716704	1129,716704	1063,57404	5621,924598	11243,8492	20,68193594	10,63878785	-3,351920986
Vessel 2	DDN+2	21	MER-TRI-MER	34343,6	314,8	136,2166667	2,311024104	2705,6	19,98869379	10,28218409	0,116351271	1,155512052	1155,512052	1087,859121	5761,61992	11523,23984	20,79618865	10,69755944	-3,882898322
Vessel 2	DDN+2	22	MER-TRI-MER	30495,6	301,96	148,7333333	2,030210668	2703,4	19,98869379	10,28218409	0,111696382	1,015105334	1015,105334	955,6729373	4988,407259	9976,814518	20,12540826	10,35251001	-0,679312754
Vessel 2	DDN+2	23	MER-TRI-MER	34642,1	311,8	139,6	2,233524355	2701,9	19,98869379	10,28218409	0,115400274	1,116762178	1116,762178	1051,377975	5551,368618	11102,73724	20,62314658	10,6085466	-3,076411186
Vessel 2	DDN+2	24	MER-TRI-MER	34662,3	321,7	138,3	2,326102675	2681,3	19,73418776	10,15126618	0,119979115	1,163051338	1163,051338	1094,956997	5802,248625	11604,49725	20,82889801	10,71438513	-5,255728091
Vessel 2	DDN+2	25	MER-TRI-PEN	36242,3	281	163,6	1,717603912	2691,5	19,73418776	10,15126618	0,104402749	0,858801956	858,801956	808,520811	4090,657796	8181,315592	19,20182543	9,877419001	2,772456898
Vessel 2	DDN+2	26	PEN-AMB-TRI-PEN	37977	298,87	135,9833333	2,197842873	2529,9	19,73418776	10,15126618	0,118135104	1,098921436	1098,921436	1034,581774	5453,761925	10907,52385	20,54057395	10,56607124	-3,925821084
Vessel 2	DDN+2	27	PEN-AMB-TRI-MER	36949,3	325,37	134,6666667	2,416113861	2397,5	19,73418776	10,15126618	0,1357122	1,208056931	1208,056931	1137,327602	6042,894335	12085,78867	21,01806176	10,81169097	-6,10843195
Vessel 2	DDN+2	28	MER-TRI-MER	34103,4	311,09	140,0166667	2,222806928	2551	19,73418776	10,15126618	0,121948256	1,110903464	1110,903464	1045,862277	5519,371593	11038,74319	20,59623901	10,59470535	-4,18547894
Vessel 2	DDN+2	29	MER-TRI-MER	33551,1	316,47	139,1333333	2,274580738	2705	20,01437935	10,29539674	0,116994455	1,137290369	1137,290369	1070,704282	5663,050048	11326,1001	20,71586348	10,65624017	-3,386217203

Vessel 2	DDN+ 2	30	MER-TRI-MER	31285,8	306,98	146,65	2,093283328	2700,5	20,01437935	10,29539674	0,113675245	1,046641664	1046,641664	985,3628779	5164,815022	10329,63004	20,28717821	10,43572447	-1,344686075
Vessel 2	DDN+ 2	31	MER-TRI-PEN	34302,7	291,2	135,45	2,149870801	2687	20,01437935	10,29539674	0,108373651	1,074935401	1074,935401	1012,000073	5321,734026	10643,46805	20,42649893	10,50739105	-2,017573276
Vessel 2	DDN+ 2	32	PEN-BARI-TRI-PAT-PEN	32478	276,3	123,35	2,239967572	2538,9	20,01437935	10,29539674	0,108826657	1,119983786	1119,983786	1054,410965	5568,939909	11137,87982	20,63785708	10,61611368	-3,021039119
Vessel 2	DDN+ 2	33	PEN-TRI-PAT-PEN	35935,5	297,9	127,6833333	2,333115781	2386	19,87618665	10,22431041	0,124853311	1,166557891	1166,557891	1098,258248	5821,114306	11642,22861	20,8440086	10,72215802	-4,643166128
Vessel 2	DDN+ 2	34	PEN-AMB-TRI-PAT	37595,3	309,5	134,7	2,297698589	2447	19,87618665	10,22431041	0,126481406	1,148849295	1148,849295	1081,586455	5725,639287	11451,27857	20,76702821	10,68255931	-4,289692047
Vessel 2	DDN+ 2	35	PEN-AMB-TRI-PEN	37422,8	290,7	125,7	2,312649165	2447,2	19,87618665	10,22431041	0,11878882	1,156324582	1156,324582	1088,62408	5766,002952	11532,0059	20,79972842	10,6993803	-4,440162657
Vessel 2	DDN+ 2	36	PEN-AMB-TRI-PEN	36381,5	274,75	131,15	2,09492947	2372,3	19,87618665	10,22431041	0,115815875	1,047464735	1047,464735	986,1377599	5169,397868	10338,79574	20,29130676	10,4378482	-2,045802768
Vessel 2	DDN+ 2	37	PEN-AMB-TRI-PEN	36817,5	284,6	131,7333333	2,160425101	2370,7	19,29582011	9,925769866	0,120048931	1,080212551	1080,212551	1016,968256	5350,860143	10701,72029	20,45190597	10,52046043	-5,652704733
Vessel 2	DDN+ 2	38	PEN-AMB-TRI-PEN	36126,6	283,7	128,7833333	2,202924809	2370,1	19,29582011	9,925769866	0,119699591	1,101462405	1101,462405	1036,973973	5467,694572	10935,38914	20,55245059	10,57218058	-6,114261022
Vessel 2	DDN+ 2	39	PEN-AMB-TRI-PEN	36204,6	284,5	134,1666667	2,120496894	2380	19,29582011	9,925769866	0,119537815	1,060248447	1060,248447	998,1730112	5240,43859	10480,87718	20,3548414	10,47053042	-5,20279804
Vessel 2	DDN+ 2	40	PEN-AMB-TRI-PEN	36631,1	290,2	132,3	2,193499622	2382,3	19,29582011	9,925769866	0,121815053	1,096749811	1096,749811	1032,537293	5441,846295	10883,69259	20,53039258	10,56083394	-6,013389476
Vessel 2	DDN+ 2	41	PEN-AMB-TRI-PEN	34324,4	271,95	128,4666667	2,116891541	2376,1	19,29582011	9,925769866	0,114452254	1,058445771	1058,445771	996,4758777	5230,436676	10460,87335	20,34594856	10,46595594	-5,161363915
Vessel 2	DDN+ 2	42	PEN-AMB-TRI-PEN	36907,7	285,4	131,5333333	2,169792195	2386,6	19,31764202	9,936995056	0,119584346	1,084896097	1084,896097	1021,37759	5376,672778	10753,34556	20,47430729	10,53198367	-5,649349961
Vessel 2	DDN+ 2	43	PEN-AMB-TRI-PEN	37277,4	298,05	131,45	2,267402054	2381,9	19,31764202	9,936995056	0,125131198	1,133701027	1133,701027	1067,325089	5643,571116	11287,14223	20,69982464	10,64798979	-6,677267272
Vessel 2	DDN+ 2	44	PEN-AMB-TRI-PEN	39482,5	293,3	131,5833333	2,2290057	2394,9	19,31764202	9,936995056	0,122468579	1,11450285	1114,50285	1049,250927	5539,035918	11078,07184	20,61279393	10,6032212	-6,283242913
Vessel 2	DDN+ 2	45	PEN-AMB-TRI-PEN	36500,4	304,2	127,8333333	2,379661017	2379,5	19,71658878	10,14221327	0,127841984	1,189830508	1189,830508	1120,168301	5945,826677	11891,65335	20,94268256	10,77291591	-5,854521153

Vessel 2	DDN+ 2	46	PEN-TOU-PEN	34752,3	332,45	137,7666667	2,413138156	2383,3	19,71658878	10,14221327	0,139491461	1,206569078	1206,569078	1135,92686	6034,99041	12069,98082	21,01196931	10,80855701	-6,164964878
Vessel 2	DDN+ 2	47	PEN-TOU-PEN	33678,4	312,6	142,5	2,193684211	2385	19,71658878	10,14221327	0,131069182	1,096842105	1096,842105	1032,624183	5442,352863	10884,70573	20,53082587	10,56105683	-3,965924691
Vessel 2	DDN+ 2	48	PEN-TOU-PEN	33400,6	304	152,6833333	1,991049012	2727,3	19,71658878	10,14221327	0,111465552	0,995524506	995,5245061	937,238528	4878,077694	9756,155387	20,02129935	10,29895638	-1,521932022

Table A 4 Speed and Displacement Corrections calculation of Test Vessel 2

	Unit	Pre-Period	Post-Period	SPEED CORRECTION TO POST-PERIOD	DISPLACEMENT CORRECTION TO POST-PERIOD
Sample Size	**pcs**	47	48	48	48
disp total	**tons**	1632479,70	1717501,70	1717501,70	1717501,70
disp avr.	**tons**	34733,6106	35781,28542	35781,28542	34733,61064
fuel total	**tons**	14140,80	14530,96	14940,92	14588,90
fuel avr	**tons**	300,868085	302,7283333	311,269243	303,9355195
mile total	**miles**	122859,00	121185,60	121185,60	121185,60
hours total	**hrs**	6425,45	6580,466667	6123,046209	6123,046209
speed avr	**knots**	19,79	19,61	19,79	19,79
cons per Nm	**tons**	0,11521607	0,120073508	0,123289596	0,120384806

	Speed loss	
Analysis 1	Pre-Period	-3,682089051
	Post-Period	-4,591029819
	Performance	-0,91%

	Fuel Consumption changes for the same period of anaylsis 1	
Analysis 2	Pre-Period	0,115216067
	Speed and Displacement Corrected Post- period	0,120384806
	Performance	4,49%

Table A 5 Dataset of Test Vessel 3

															ISO AND LCV CORRECTED		ACC TO 18557,6 DISP		ACC TO 18557,6 DISP
Ship	Year	Voyage	Ports	Round Trip Displacement	Round Trip Cons	Round trip duration	Round trip av. Cons per hour	Total Distance	Total Av speed	Av speed in m/s	Total av cons/mile	Av.Cons per engine	Av.cons per engine in kg	LCV corrected	Brake Power for one engine	brake power for 2 engine	expected speed in knots	expected speed in m/s	speed loss
Vessel 3	DDN +1	18	PEN - TRI - MER	34784	296,5	126,65	2,341097513	2535	19,81425272	10,1924516	0,116962525	1,170548756	1170,548756	1102,015457	5842,561781	11685,12356	20,86112772	10,7309641	-5,018304911
Vessel 3	DDN +1	19	MER - TRI - MER	32923,3	315	136,7	2,30431602	2694	19,81425272	10,1924516	0,116926503	1,15215801	1152,15801	1084,701452	5743,516069	11487,03214	20,78153925	10,69002379	-4,654547064
Vessel 3	DDN +1	20	MER - TRI - MER	33433,3	308	137,7	2,23674655	2694	19,81425272	10,1924516	0,114328137	1,118373275	1118,373275	1052,894746	5560,157934	11120,31587	20,63051072	10,61233471	-3,956557365
Vessel 3	DDN +1	21	MER - TRI - MER	35005,8	329,3	133,2	2,472222222	2694	19,81425272	10,1924516	0,122234595	1,236111111	1236,111111	1163,739266	6191,26555	12382,5311	21,13097299	10,86977251	-6,231233511
Vessel 3	DDN +1	22	MER - TRI - MER	35044	334	131,8	2,53414264	2694	19,9645627	10,26977105	0,123979213	1,26707132	1267,07132	1192,886817	6353,548517	12707,09703	21,2514137	10,93172721	-6,055366583
Vessel 3	DDN +1	23	MER - TRI - MER	34561	312,1	153,5	2,033224756	2694	19,9645627	10,26977105	0,115850037	1,016612378	1016,612378	957,0917468	4996,873454	9993,746908	20,13330174	10,35657041	-0,838109126
Vessel 3	DDN +1	24	MER - TRI - MER	35279,7	321,1	138,2	2,323444284	2694	19,9645627	10,26977105	0,119190794	1,161722142	1161,722142	1093,705623	5795,092262	11590,18452	20,82315321	10,71143001	-4,123249294
Vessel 3	DDN +1	25	MER - TRI - MER	32413,2	303,6	136,2	2,22907489	2694	19,9645627	10,26977105	0,112694878	1,114537445	1114,537445	1049,283496	5539,224819	11078,44964	20,61295268	10,60330286	-3,14554637
Vessel 3	DDN +1	26	MER - TRI - MER	33376	303,8	140	2,17	2694	19,9645627	10,26977105	0,112769117	1,085	1085	1021,47541	5377,245024	10754,49005	20,47480269	10,53223851	-2,492038652
Vessel 3	DDN +1	27	MER - TRI - MER	32978,1	299,2	138,2	2,164978292	2694	19,91665884	10,24512931	0,111061618	1,082489146	1082,489146	1019,111561	5363,411614	10726,82323	20,46281215	10,52607057	-2,669004145
Vessel 3	DDN +1	28	MER - TRI - MER	32704	304,7	133,3	2,285821455	2694	19,91665884	10,24512931	0,113103192	1,142910728	1142,910728	1075,99558	5693,509775	11387,01955	20,7408336	10,6690848	-3,973681939
Vessel 3	DDN +1	29	MER - TRI - MER	32967,8	308,1	140,8	2,188210227	2694	19,91665884	10,24512931	0,114365256	1,094105114	1094,105114	1030,047437	5427,324775	10854,64955	20,51795442	10,55443575	-2,930582466

Vessel 3	DDN +1	30	MER - TRI - MER	33789,5	328,3	131,4	2,49847793	2694	19,91665884	10,24512931	0,1218634	1,249238965	1249,238965	1176,09851	6260,264071	12520,52814	21,18256256	10,89631018	-5,976159473
Vessel 3	DDN +1	31	MER - TRI - MER	34575,9	331,9	132,2	2,510590015	2694	20,25454835	10,41893967	0,123199703	1,255295008	1255,295008	1181,799984	6292,001273	12584,00255	21,20610155	10,90841864	-4,487167025
Vessel 3	DDN +1	32	MER - TRI - MER	35342,2	372,9	131,2	2,84222561	2694	20,25454835	10,41893967	0,138418708	1,421112805	1421,112805	1337,909479	7138,249224	14276,49845	21,79349571	11,21057419	-7,061498422
Vessel 3	DDN +1	33	MER - TRI - MER	33581	343,4	131,5	2,611406844	2694	20,25454835	10,41893967	0,127468448	1,305703422	1305,703422	1229,257086	6553,900346	13107,80069	21,39593376	11,00606833	-5,334590295
Vessel 3	DDN +1	34	MER - TRI - MER	34093,9	300,7	137,3	2,190094683	2694	20,25454835	10,41893967	0,111618411	1,095047342	1095,047342	1030,9345	5432,499645	10864,99929	20,52239068	10,55671776	-1,305122426
Vessel 3	DDN +1	35	MER - TRI - MER	35210,2	326,3	130,9	2,492742552	2694	20,08073596	10,32953058	0,12112101	1,246371276	1246,371276	1173,398719	6245,215291	12490,43058	21,17135937	10,89054726	-5,151409483
Vessel 3	DDN +1	36	MER - TRI - MER	34087	309,7	132,6	2,335595777	2694	20,08073596	10,32953058	0,114959169	1,167797888	1167,797888	1099,425647	5827,78095	11655,5619	20,84933658	10,72489874	-3,686451207
Vessel 3	DDN +1	37	MER - TRI - MER	34438	303	135,75	2,232044199	2694	20,08073596	10,32953058	0,11247216	1,116022099	1116,022099	1050,681227	5547,329746	11094,65949	20,6197587	10,60680387	-2,614107877
Vessel 3	DDN +1	38	MER - TRI - MER	35034	335,7	131,5	2,552851711	2694	20,08073596	10,32953058	0,124610245	1,276425856	1276,425856	1201,693663	6402,281001	12804,562	21,28698112	10,95002309	-5,666586297
Vessel 3	DDN +1	39	MER - TRI - MER	34476	309,1	134,25	2,302420857	2694	20,08073596	10,32953058	0,114736451	1,151210428	1151,210428	1083,809349	5738,398128	11476,79626	20,7773895	10,68788916	-3,352940679
Vessel 3	DDN +1	40	MER - TRI - MER	34459	328,7	127,5	2,578039216	2694	20,05412591	10,31584237	0,122011878	1,289019608	1289,019608	1213,550076	6467,667705	12935,33541	21,33428063	10,97435396	-6,000458832
Vessel 3	DDN +1	41	MER - TRI - MER	34545	299,4	134,3	2,229337305	2694	20,05412591	10,31584237	0,111135857	1,114668652	1114,668652	1049,407022	5539,941239	11079,88248	20,61355469	10,60361253	-2,713887968
Vessel 3	DDN +1	42	MER - TRI - MER	34131	312,7	133,6	2,340568862	2694	20,05412591	10,31584237	0,116072754	1,170284431	1170,284431	1101,766607	5841,142046	11682,28409	20,85999645	10,73038217	-3,86323432
Vessel 3	DDN +1	43	MER - TRI - MER	35202	311,6	133,9	2,327109783	2694	20,05412591	10,31584237	0,115664439	1,163554892	1163,554892	1095,431069	5804,959013	11609,91803	20,83107193	10,7155034	-3,72974576
Vessel 3	DDN +1	44	MER - TRI - MER	35433	300,4	135,8	2,212076583	2694	19,95209077	10,26335549	0,111507053	1,106038292	1106,038292	1041,281951	5492,759119	10985,51824	20,57374043	10,58313208	-3,021568512
Vessel 3	DDN +1	45	MER - TRI - MER	35062	304,1	136,4	2,229472141	2694	19,95209077	10,26335549	0,112880475	1,11473607	1114,73607	1049,470492	5540,309345	11080,61869	20,61386398	10,60377163	-3,210330727
Vessel 3	DDN +1	46	MER - TRI - MER	33264	296,9	132,9	2,234010534	2694	19,95209077	10,26335549	0,110207869	1,117005267	1117,005267	1051,606832	5552,695054	11105,39011	20,62425868	10,60911867	-3,259113093

Vessel 3	DDN +1	47	MER - TRI - MER	30138	286,5	139	2,061151079	2694	19,95209077	10,26335549	0,106347439	1,03057554	1030,57554	970,2373932	5075,142682	10150,28536	20,20564927	10,39378598	-1,25488916
Vessel 3	DDN +1	48	MER - TRI - MER	32917	294,9	138,9	2,123110151	2694	19,95209077	10,26335549	0,109465479	1,061555076	1061,555076	999,4031391	5247,685004	10495,37001	20,36127369	10,47383919	-2,009613612
Vessel 3	DDN +1	1	MER - TRI - MER	31888	296,5	138,2	2,145441389	2694	19,78527507	10,17754549	0,110059391	1,072720695	1072,720695	1009,915033	5309,497188	10618,99438	20,41578309	10,50187882	-3,088336235
Vessel 3	DDN +1	2	MER - TRI - MER	31408	299,2375	141,3	2,117745931	2694	19,78527507	10,17754549	0,111075538	1,058872965	1058,872965	996,878061	5232,807378	10465,61476	20,34805792	10,46704099	-2,765781664
Vessel 3	DDN +1	3	MER - TRI - MER	33868	299,575	133,4	2,245689655	2694	19,78527507	10,17754549	0,111200817	1,122844828	1122,844828	1057,104498	5584,530716	11169,06143	20,65087074	10,62280791	-4,191569843
Vessel 3	DDN +1	4	MER - TRI - PEN	36260	302,4796875	124,9	2,42177492	2531	19,78527507	10,17754549	0,119509952	1,21088746	1210,88746	1139,99241	6057,921216	12115,84243	21,02962275	10,81763794	-5,917118415
Vessel 3	DDN +1	5	PEN - TRI - PEN	36550	272,1	122,1	2,228501229	2372	19,5449191	10,05390638	0,114713322	1,114250614	1114,250614	1049,013459	5537,658567	11075,31713	20,61163629	10,60262571	-5,175315439
Vessel 3	DDN +1	6	PEN - TRI - MER	35464	306,4	152,7	2,006548788	2535	19,5449191	10,05390638	0,12086785	1,003274394	1003,274394	944,5346756	4921,818129	9843,636258	20,06285258	10,32033137	-2,581554572
Vessel 3	DDN +1	7	MER - TRI - PEN	35772	309,9490234	128,9	2,404569615	2531	19,5449191	10,05390638	0,122461092	1,202284808	1202,284808	1131,893426	6012,211338	12024,42268	20,99436614	10,79950194	-6,903980992
Vessel 3	DDN +1	8	PEN - TRI - PEN	36761	293,8	125,5	2,341035857	2372	19,5449191	10,05390638	0,12386172	1,170517928	1170,517928	1101,986434	5842,396204	11684,79241	20,8609958	10,73089624	-6,308791378
Vessel 3	DDN +1	9	PEN - TRI - PEN	36615	290,9	127,8	2,276212833	2372	19,23453947	9,894247104	0,122639123	1,138106416	1138,106416	1071,472551	5667,475772	11334,95154	20,71949991	10,65811075	-7,166970444
Vessel 3	DDN +1	10	PEN - TOU - PEN	36646,1	312,1426514	144	2,167657301	2732	19,23453947	9,894247104	0,114254265	1,083828651	1083,828651	1020,372641	5370,792791	10741,58558	20,46921386	10,52936361	-6,031860311
Vessel 3	DDN +1	11	PEN - TOU - PEN	35681,9	307,2051514	150	2,048034342	2732	19,23453947	9,894247104	0,112446981	1,024017171	1024,017171	964,0630043	5038,419086	10076,83817	20,17184408	10,3763966	-4,646598535
Vessel 3	DDN +1	12	PEN - TRI - PEN	36605	290,9	122,9	2,366965012	2372	19,23453947	9,894247104	0,122639123	1,183482506	1183,482506	1114,191961	5911,894959	11823,78992	20,91604183	10,75921192	-8,039295253
Vessel 3	DDN +1	13	PEN - TRI - PEN	33711	275,1	124,2	2,214975845	2372	19,23453947	9,894247104	0,115978078	1,107487923	1107,487923	1042,646709	5500,692546	11001,38509	20,58045885	10,58658803	-6,539792857
Vessel 3	DDN +1	14	PEN - TRI - PEN	32504	267,8	123,3	2,171938362	2372	19,23230378	9,893097065	0,112900506	1,085969181	1085,969181	1022,387847	5382,581982	10765,16396	20,47942043	10,53461387	-6,089609082
Vessel 3	DDN +1	15	PEN - TRI - PEN	36376,9	282	125,7	2,243436754	2372	19,23230378	9,893097065	0,118887015	1,121718377	1121,718377	1056,043999	5578,393856	11156,78771	20,64575264	10,62017516	-6,846196804

Vessel 3	DDN +1	16	PEN - TRI - PEN	37507	277,8	123,6	2,247572816	2372	19,23230378	9,893097065	0,117116358	1,123786408	1123,786408	1057,990951	5589,658857	11179,31771	20,65514326	10,62500569	-6,888548094
Vessel 3	DDN +2	17	PEN - TRI - PEN	32673	272,7	124,2	2,195652174	2372	19,23230378	9,893097065	0,114966273	1,097826087	1097,826087	1033,550555	5447,752722	10895,50544	20,53544214	10,56343144	-6,345801313
Vessel 3	DDN +2	18	PEN - TRI - AMB - PEN	33661,4	292,5	125,2	2,336261981	2391	19,33945723	9,9482168	0,122333752	1,16813099	1168,13099	1099,739246	5829,5714	11659,1428	20,85076647	10,72563427	-7,248219105
Vessel 3	DDN +2	6	PEN-AMB-TRI-PEN	38408,8	275,65	131,2166667	2,100723993	2382,5	18,9905984	9,768763817	0,115697796	1,050361997	1050,361997	988,8653927	5185,52117	10371,04234	20,30580276	10,44530494	-6,476987759
Vessel 3	DDN +2	7	PEN-AMB-TRI-PEN	38501,8	274,6	130,1333333	2,110143443	2385,5	18,9905984	9,768763817	0,115112136	1,055071721	1055,071721	993,2993723	5211,702275	10423,40455	20,32924569	10,45736398	-6,584835013
Vessel 3	DDN +2	8	PEN-TRI-PEN	38048,5	277,4	129,1	2,148721921	2388,1	19,27715268	9,916167339	0,11615929	1,07436096	1074,36096	1011,459265	5318,560844	10637,12169	20,42372253	10,50596287	-5,613912211
Vessel 3	DDN +2	9	PEN-TRI-PEN	36881,3	271,2	126,5333333	2,143308746	2376,6	19,27715268	9,916167339	0,114112598	1,071654373	1071,654373	1008,911143	5303,602688	10607,20538	20,41061244	10,49921904	-5,553286384
Vessel 3	DDN +2	11	PEN-TRI-PEN	36259,5	267,9	122,7833333	2,181892222	2369,2	19,27715268	9,916167339	0,113076144	1,090946111	1090,946111	1027,073388	5409,964681	10819,92936	20,50304117	10,54676438	-5,979056865
Vessel 3	DDN +2	12	PEN-TRI-PEN	37380,2	276,6	125,9833333	2,195528509	2382,7	19,49600789	10,02874646	0,116086792	1,097764255	1097,764255	1033,492343	5447,413446	10894,82689	20,53515223	10,56328231	-5,060319645
Vessel 3	DDN +2	13	PEN-TRI-PEN	36991,9	274,01	124,6666667	2,197941176	2365,3	19,49600789	10,02874646	0,11584577	1,098970588	1098,970588	1034,628048	5454,031532	10908,06306	20,54080405	10,56618961	-5,086442404
Vessel 3	DDN +2	14	PEN-TRI-PEN	37481,5	271,1	125,4333333	2,161307467	2377,2	19,49600789	10,02874646	0,11404173	1,080653734	1080,653734	1017,383609	5353,293148	10706,5863	20,45402204	10,52154894	-4,683744619
Vessel 3	DDN +2	15	PEN-TRI-PEN	36269,4	272,7	123,1166667	2,214972249	2373,5	19,49600789	10,02874646	0,114893617	1,107486124	1107,486124	1042,645016	5500,682705	11001,36541	20,58045052	10,58658375	-5,269285208
Vessel 3	DDN +2	16	PEN-TRI-PEN	36954,5	281,5	126,0166667	2,233831504	2385,7	19,52404783	10,0431702	0,117994719	1,116915752	1116,915752	1051,522558	5552,206618	11104,41324	20,6238492	10,60890803	-5,332667818
Vessel 3	DDN +2	17	PEN-TRI-PEN	37800	271,3	125,6666667	2,158885942	2391,4	19,52404783	10,0431702	0,113448189	1,079442971	1079,442971	1016,243734	5346,615377	10693,23075	20,44821183	10,51856017	-4,519534562
Vessel 3	DDN +2	18	PEN-TRI-PEN	37506,5	279,3	124,6333333	2,240973522	2377,5	19,52404783	10,0431702	0,117476341	1,120486761	1120,486761	1054,884492	5571,681742	11143,36348	20,64014833	10,6172923	-5,407424792
Vessel 3	DDN +2	19	PEN-TRI-PEN	37411,1	263,8	123,9666667	2,127991396	2384,1	19,52404783	10,0431702	0,110649721	1,063995698	1063,995698	1001,700868	5261,213126	10522,42625	20,37325822	10,48000403	-4,16826008
Vessel 3	DDN +2	20	PEN-TRI-PEN	36948,8	274,1	121,4333333	2,2572056	2372,2	19,52404783	10,0431702	0,11554675	1,1286028	1128,6028	1062,525353	5615,868314	11231,73663	20,67691869	10,63620698	-5,575641511

Vessel 3	DDN +2	21	PEN-TRI-PEN	37282,7	272,9	123,3166667	2,213001757	2370,1	19,66584335	10,11610982	0,115142821	1,106500878	1106,500878	1041,717455	5495,291092	10990,58218	20,57588568	10,5842356	-4,422858611
Vessel 3	DDN +2	22	PEN-TRI-PEN	37589,9	284,2	122,65	2,317162658	2373,8	19,66584335	10,11610982	0,11972365	1,158581329	1158,581329	1090,748698	5778,170992	11556,34198	20,80954134	10,70442807	-5,49602691
Vessel 3	DDN +2	23	PEN-PAT-TRI-PEN	37572,4	293,2	129,5666667	2,262927708	2438,5	19,66584335	10,11610982	0,120237851	1,131463854	1131,463854	1065,218898	5631,419846	11262,83969	20,68979129	10,64282864	-4,949049121
Vessel 3	DDN +2	24	PEN-PAT-TRI-PEN	37323,3	283,38	136,1833333	2,080871374	2445,7	19,66584335	10,11610982	0,115868667	1,040435687	1040,435687	979,5202488	5130,225459	10260,45092	20,25589877	10,41963433	-2,913005347
Vessel 3	DDN +2	26	PEN-TOU-PEN	36114	311,77	147,7333333	2,110356498	2727,1	19,90644329	10,23987443	0,114322907	1,055178249	1055,178249	993,3996631	5212,294048	10424,5881	20,32977421	10,45763585	-2,082319828
Vessel 3	DDN +2	27	PEN-TOU-PEN	35196,1	316,64	140,1666667	2,25902497	2732,4	19,90644329	10,23987443	0,115883472	1,129512485	1129,512485	1063,381778	5620,814411	11241,62882	20,68101663	10,63831495	-3,745334932
Vessel 3	DDN +2	28	PEN-TOU-PEN	34520,6	309,19	143,7333333	2,151136364	2726	19,90644329	10,23987443	0,113422597	1,075568182	1075,568182	1012,595806	5325,228873	10650,45775	20,42955486	10,50896302	-2,560562742
Vessel 3	DDN +2	29	PEN-TOU-PEN	34057,6	301,5	144,1	2,092297016	2723,7	20,07465023	10,32640008	0,11069501	1,046148508	1046,148508	984,8985953	5162,068621	10324,13724	20,2847023	10,43445086	-1,035519576
Vessel 3	DDN +2	30	PEN-TOU-PEN	33235	300,27	144,6	2,076556017	2727	20,07465023	10,32640008	0,110110011	1,038278008	1038,278008	977,4888977	5118,185048	10236,3701	20,24496108	10,41400798	-0,841250561
Vessel 3	DDN +2	31	PEN-TOU-PEN	33819,2	294,13	141,9	2,072797745	2731,2	20,07465023	10,32640008	0,107692589	1,036398872	1036,398872	975,7197816	5107,69293	10215,38586	20,23540889	10,40909433	-0,794442337
Vessel 3	DDN +2	32	PEN-TRI-MER	29326,2	266,32	130,1	2,047040738	2536,5	20,07465023	10,32640008	0,104995072	1,023520369	1023,520369	963,5952888	5035,634445	10071,26889	20,16927069	10,37507285	-0,469131787
Vessel 3	DDN +2	33	MER-TRI-MER	32746,7	295,73	136,8666667	2,160716025	2695,5	19,94862841	10,26157445	0,109712484	1,080358013	1080,358013	1017,105202	5351,662361	10703,32472	20,45260379	10,52081939	-2,464113569
Vessel 3	DDN +2	34	MER-TRI-MER	32790,7	292,64	141,5	2,068127208	2695,5	19,94862841	10,26157445	0,108566129	1,034063604	1034,063604	973,5212387	5094,646154	10189,29231	20,22350349	10,40297019	-1,359186255
Vessel 3	DDN +2	35	MER-TRI-MER	32710,7	297,38	139,9666667	2,124648726	2696,8	19,94862841	10,26157445	0,110271433	1,062324363	1062,324363	1000,127386	5251,950112	10503,90022	20,36505547	10,47578454	-2,044811836
Vessel 3	DDN +2	36	MER-TRI-MER	33562,7	308,45	142,8	2,160014006	2701,2	19,94862841	10,26157445	0,11418999	1,080007003	1080,007003	1016,774743	5349,726497	10699,45299	20,45091967	10,51995308	-2,456081514
Vessel 3	DDN +2	37	MER-TRI-MER	33193,4	305,73	135,9666667	2,248565825	2696,1	19,94862841	10,26157445	0,113397129	1,124282912	1124,282912	1058,458386	5592,362407	11184,72481	20,65739415	10,62616355	-3,431051056
Vessel 3	DDN +2	41	MER-TRI-MER	34529,6	326,1	140,9666667	2,31331284	2690	20,21421856	10,39819403	0,121226766	1,15665642	1156,65642	1088,936489	5767,79268	11535,58536	20,80117305	10,70012342	-2,821737461

Vessel 3	DDN +2	42	MER-TRI-PEN	35200,3	309,2	127,7	2,421299922	2541,4	19,66227438	10,11427394	0,121665224	1,210649961	1210,649961	1139,768816	6056,660858	12113,32172	21,02865419	10,81713971	-6,497704499
Vessel 3	DDN +2	43	PEN-AMB-PAT-TRI-PEN	37651,7	308,4	137,8666667	2,236943907	2462,9	19,66227438	10,11427394	0,125218239	1,118471954	1118,471954	1052,987647	5560,696137	11121,39227	20,63096127	10,61256648	-4,695306633
Vessel 3	DDN +2	44	PEN-AMB-PAT-TRI-PEN	36004,3	293,5	133,5666667	2,197404542	2454,4	19,66227438	10,11427394	0,11958116	1,098702271	1098,702271	1034,37544	5452,559713	10905,11943	20,53954772	10,56554335	-4,271142447
Vessel 3	DDN +2	45	PEN-TOU-PEN	36284,9	336,45	157,7333333	2,133030431	2820,6	19,66227438	10,11427394	0,119283131	1,066515216	1066,515216	1004,072873	5275,168589	10550,33718	20,38558908	10,48634702	-3,548166798
Vessel 3	DDN +2	46	PEN-MARSEILLES-PEN	37123,8	347,8	144,9833333	2,398896425	2821,1	19,67155987	10,1190504	0,123285243	1,199448212	1199,448212	1129,222907	5997,113308	11994,22662	20,98266193	10,7934813	-6,248502041
Vessel 3	DDN +2	48	PEN-AMB-PAT-TRI-PEN	36298,3	290,5	134,2833333	2,163336229	2452,2	19,67155987	10,1190504	0,118465052	1,081668115	1081,668115	1018,3386	5358,886005	10717,77201	20,45888272	10,52404927	-3,848317895
Vessel 3	DDN +2	49	PEN-AMB-PAT-TRI-PEN	31849,6	267,3	144,45	1,85046729	2443,4	19,67155987	10,1190504	0,109396742	0,925233645	925,2336449	871,0630568	4476,979654	8953,959308	19,62189686	10,09350374	0,253099953
Vessel 3	DDN +2	50	PEN-AMB-TRI-PEN	34630,7	269,91	133,7666667	2,017767256	2422,1	19,67155987	10,1190504	0,111436357	1,008883628	1008,883628	949,8155001	4953,416918	9906,833836	20,0926422	10,33565515	-2,095704093
Vessel 3	DDN +2	48	PEN-TOU-PEN	33400,6	304	152,6833333	1,991049012	2727,3	19,71658878	10,14221327	0,111465552	0,995524506	995,5245061	937,238528	4878,077694	9756,155387	20,02129935	10,29895638	-1,521932022

Table A 6 Speed and Displacement Corrections calculation of Test Vessel 3

	Unit	Pre-Period	Post-Period	SPEED CORRECTION TO POST	DISPLACEMENT CORRECTION TO POST
Sample Size	**pcs**	47	42	42	42
disp total	**tons**	1618866,80	1493193,20	1493193,20	1493193,20
disp avr.	**tons**	34443,97447	35552,21905	35552,21905	34443,97447
fuel total	**tons**	14415,49	12182,95	12476,46	12150,63
fuel avr	**tons**	306,7125322	290,0702381	297,0585333	289,3008212
mile total	**miles**	123474,00	105927,00	105927,00	105927,00
hours total	**hrs**	6295,65	5619,233333	5345,622561	5345,622561
speed avr	**knots**	19,82	19,66	19,82	19,82
cons per Nm	**tons**	0,116805063	0,115064212	0,117783553	0,114707624

Analysis 1	Speed loss		
	Pre-Period		-4,446136522
	Post-Period		-3,934894743
	Performance		0,51%

Analysis 2	Fuel Consumption changes for the same period of anaylsis 1		
	Pre-Period		0,116805063
	Speed and Displacement Corrected Post- period		0,114707624
	Performance		-1,80%