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Ship performance indicator

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1. Introduction

Merchant shipping remains the largest carrier of freight throughout recorded history due to the economic advantages involved. Optimum management of the global propulsion power may result in large cut down of marine fuel grades, which in turn will benefit environment and the economics of the shipping community. The most important OPEX cost factor is the marine fuel (*Journee and Maijers* [1]), the price of which affects world trading patterns and modes and frequently is the fora main topic.

Although, water transport is still the most efficient mode (small ratio of CO_2 per cargo ton per mile) the aim is for further vessel's energy efficiency optimization, bunker minimization and in turn reduction of CO_2, NO_x, SO_x. An energy efficiency management scheme cannot be sustained unless a meaningful and practical mode of monitoring is applied. Along these lines, Kariranta [2] presents the "*Onboard-NAPA*" computer software/hardware for online collection of data, assessment of the hydrodynamic situation and the provision of recommendations to crew and the office.

From the scientific standpoint, vessel's sailing is a complex hydrodynamic motion through liquid (sea water) and atmospheric air medium, affected by the complex wave formation at the boundaries of the hull with specific characteristics imposing difficulties in accurately simulating the phenomenon of turbulence and assessing its effect on main engine power requirements. Journee and Maijers [1], recognizing the importance of accurately predicting the power and speed of the vessel for a given set of meteorological forecast, worked on a computer software to simulate the effect of added resistance due to rough sea and resulted steering as well as the effect on the vertical motion resistance due to slamming.

Townsin and Kwon [3] provide approximate relationships for the practical estimation of the percentage of speed loss as a function of the ***Beaufort*** number. Henk van den Boom et al. [4] focus on the importance of accurate and transparent speed trial methodology and determine the boundary conditions and the correction methods for deviated parameters to be applied. Means of obtaining robust benchmarking level facilitates future practical reference and monitoring of vessel's performance.

Kokarakis et al. [5], involving financial aspects of shipping, suggest an expression for the daily Time Charter Equivalent (TCE) as a function of the effective power and the vessel's speed, which is given as:

$$TCE = \frac{FR_v}{d} - c_R - pb^* f(P_E, V_S) \quad (1)$$

where FR_v is the freight rate, d the voyage distance, c_R the daily operating expenses and pb the price of bunkers. As individual vessel speed trial determines the power versus speed function (Van den Boom et al. [4]), they showed that the abovementioned relationship can provide an optimum speed for given financial and environmental restraints.

From a different viewpoint, Devanney [6] brought out the uneconomic charter party speed clause, which today's VLCC market is required to maintain a value in the range of 13–13.5 knots. The implication of such a requirement has an indirect but significant impact on CO_2 emissions. As super slow steaming of about 8 knots is the point of equilibrium on today's freight rate versus trading speed plane, only bilateral (charterer – Owner) understanding can result in environmental benefits.

International bodies have attempted to control the matter of energy efficiency by passing relevant regulation (IMO, MEPC.1/Circ.683) and guidelines (INTERTANKO [7]) to the international shipping community, recommending that appropriate procedure is in place for the monitoring of the fuel consumption and the harmful emissions across the entire fleet, appropriately recorded, aiming for the mitigation of environmental pollution.

The present study proposes a ship performance indicator (***PDno***) and claims an effective monitoring by utilizing basic propulsion parameters without involving a complicated algorithm. There have been a number of performance indicators in literature that are not completely independent from environmental effects,

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Nomenclature

foc	Fuel oil consumption rate, Kg per day
NCV	Net calorific value, MJ/kg
ρ	Seawater density, kg/m^3
D_p	Propeller diameter, m
V_S	Vessel speed through water, nautical miles per hour
V_M	Mean flow velocity through propeller disk, nautical miles per hour
V_G	Vessel transporting speed measured by the GPS, nautical miles per hour
N	Main engine revolution rate, s^{-1}
p	Propeller pitch, m
S	Slip, vessel's actual speed to propeller advance speed ratio
T	Propeller thrust force, N
p_r	Power ratio
P_T	Thrust power, kW
P_C	Fuel oil input power, kW
P_E	Effective towing power, kW
P_{eng}	Main engine maximum continuous power, kW
L	Vessel overall length, m
B	Vessel breath, m
D	Vessel depth, m

Notation

MCR	Main engine maximum continuous rating, kW
DWT	Deadweight tonnage, metric tons
IMO	International Maritime Organization
"Sailing" report:	24 h average navigational and machinery parameter values
VLCC	Tanker 309–320 K DWT
AFRAMAX	Tanker 105–115 K DWT
CAPESIZE	Bulk carrier 180K DWT
SUPRAMAX	Bulk carrier 57K DWT
OPEX	Daily operating expenses
KPI	Key performance indicator

loading and operational conditions. The novelty of the ***PDno*** is shown through its application on a large number of data, collected from quite wide range of hull, propeller and main engine sizes.

PDno serves a three-fold purpose. Firstly, it can be utilized in the framework of an environmental and energy efficiency regulatory policy to provide a shipping indexation. This is achieved by means of target identification during sea trials, recording during operational lifetime and verification during the occasional survey by the authorities. The proposed policy framework may also include an incentivizing strategy for main engine efficiency improvement, hull resistance and/or wake optimization resulting in the reduction of the baseline value of ***PDno***.

Secondly, ***PDno*** provides the reciprocating interaction between the "Vessel" and the Office. Its constant value may be aimed and a significant deviation from a baseline value can accurately presignify machinery and/or hydrodynamic shortcomings.

Thirdly, ***PDno*** provides a commercial tool for defining the charter-party speed versus fuel oil consumption framework.

2. Theory

A key performance indicator (***KPI***) is devised, that compares the chemical energy of the consumed fuel with the produced propulsion effect. On the basis of the hydrodynamic fundamentals, a group of parameters, extracted from a daily "sailing" report, is utilized to provide a unique value, which satisfies below comprehensive set of constrains.

2.1. The KPI requirements:

1. Dimensionless number
2. Unique value for an individual vessel
3. Base value easy and accurately to determine, utilizing common speed trial data
4. Inclusive of the hull resistance effects (wave, wind, swell, current)
5. Statistically constant between characteristic periods of time (dry-docking, major main engine overhauling, hull & propeller cleaning)
6. Capable of providing diagnosis on the
   a. efficient operation of the main engine (inferior quality bunkers, poor combustibility)
   b. hull and propeller roughness
7. Specific for crew to grasp
8. Measurable, achievable, realistic and timely available

2.2. The marine propulsion

Propeller throughput water flow is responsible for the applied thrust on the shaft and in turn on the vessel (MAN Diesel and Turbo [8]), producing a variable degree of wake yielding. This flow strain is due to hull resistance (Journee and Maijers [1]) as well as the energy loss into dissipated turbulence and its value is reflected on the apparent slip ratio **S** (Fig. 1):

$$1 - S = \frac{V_G}{N * p} \tag{2}$$

The slip ratio is based on the actual vessel transporting speed ($\boldsymbol{V_G}$), with which vessel moves from one position to the other (speed over ground, SOG). This way the effect of the current as well as the wave, wind and hull roughness is also taken into account. The apparent slip reflects the actual effective power as percentage of the theoretical "frictionless" sailing with a velocity reference point far away into the undisturbed sea region. Vessel navigating speed may be different from its transporting one since water current tends to alter vessel's position. The resistance, owed to current, is related to the vessel drifting and in turn millage increase. By involving only real slip (based on speed through water, STW) a part of resistance is neglected. Thus, ***S*** recapitulates the required load on the propeller in order for the vessel to maintain constant operational speed ($\boldsymbol{V_G}$).

2.3. The propulsion diagnosis number (PDno)

Application of the steady state energy continuity equation on the reference volume that surrounds the propeller determines the power transmission to the water and the resulted thrust. The mean flow velocity through the propeller disk ($\boldsymbol{V_M}$) is related to the speed of the vessel ($\boldsymbol{V_S}$), affected by the wake of the hull, due to hull shape and roughness (steel plating inherent irregularity,