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MANAGERIAL INSTRUMENTS FOR ENERGY EFFICIENCY IMPROVEMENT ONBOARD TO OPERATING SHIPS

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Abstract: *The operating ship, and especially those ones older than 10 years, is the most affected by the IMO enforced standards, because of the deficiency and insufficient applicable instruments as existing in the international practice, due to the technique misalignments and the implementation costs impact against the freight rate levels. Once the structure of the world fleet counts 32% share of the old ships as reported for 2015, the conception of new improvement methods becomes very important and most of the specialized companies and seeking for practical solutions in respect of energy efficiency. Overcoming these needs, the approached research as presented in the paperwork is proposing a new algorithm for cost-benefit analysis, conceived by the authors as a pragmatic solution for optimizing the energy efficiency onboard the old operating ships, exceeding 10 years in service.*

Keywords: *maritime transportation, energy efficiency, EEDI, CO_2 emissions, cost-benefit analysis.*

1. Introduction

Starting on 2015 IMO has enforced energy efficiency standards for those ships exceeding a gross tonnage of 400tdw [6]. In respect of these limitations and due to the energy efficiency imperatives, the ship owners and the charterers/freighters have to analyse and to decide about new managerial methods to reduce the fuel consumption with significant effect against the CO_2 emissions. The managerial analysis regarding the energy efficiency for the older ships in service is a complex endeavour, taking into account several variables as following: the compatibility of implementing measures, the potential for energy efficiency optimization and the expected economic effects against the naval transportation activity.

The managerial method for energy efficiency improvement proposed in this paperwork is seeking for those suitable measures in case of the ships older than 10 years in service, for whom the hull and energy equipments had been projected disregarding the ecological variables. The proposed methodology contain the next algorithm as to be applied:

- The identification of the onboard energy efficiency improvement methods;
- The computation of the effective costs to implement the identified methods;
- The decision making process for the optimum method of energy efficiency implementation onboard the analyzed ship.

2. The identification of the improvement methods for EEDI

Undergoing the literature review [1,2,5,8] the authors have identified 50 operational and technological methods for CO_2 reduction, out of which only 17 measured were identified as having supporting available data regarding the emissions' decreasing level potential and the implementing costs onboard the ships in service. Searching among these 17 methods the authors have identified 2 significant methods with impact against the energy efficiency, namely:

- the reduction of the ship speed;
- the engine alternative fuelling adopting B20 mixture (20% biodiesel and 80% MGO).

2.1. The reduction of the ship speed

The propulsion power is in directly ratio to the ship speed, based on a third degree function as following [4,8]:

$$P = c \cdot V^3 \qquad (1)$$

where:

P – ship's propulsion power [kW], as about 75% from the installed engine power (MCR) at the maximum nominal speed.
c – ship building coefficient.

Taking into account the relation between the engine power and the fuel consumption it can be deducted that a square relation is stated between the ship speed and the fuel consumption.

Table 1

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Ship speed (% out of maximum speed)	Propulsion power (% out of MCR)	Fuel consumption
100%	75%	100%
90%	55%	73%
80%	38%	52%
70%	26%	35%

But the potential for speed reduction is still limited because the engines must not be operated to any decrement of engine burden, the maximum accepted reduction being not lower than 30%. On the other hand, together with the speed reduction the ship will spend longer time in the voyage trip to get the calling ports, thus affecting in a negative manner the economic profit and the voyage efficiency. For example, on a speed reduction of 10%, the ship will need in addition 11% more time in the voyage in order to cover the established distance [8]. Therefore, within the drafted methodology the authors have used as method for energy efficiency improvement the speed reduction at a mean rate of 20%.

2.2. The alternative engine fuelling adopting B20 mixture

The usage of biodiesel to fuel the naval engines hasn't been an attractive method for the managers by now, because of the low prices of the fuels on the bunker market and because of the lack of law provisions and enforcements regarding the reduction of the CO_2 emissions in maritime industry. Together with EEDI standards implementation, as deeper restricted year by year, and considering the permanent propensity for the prices' increment on the naval classic fuels market, the alternative fuelling mixtures become interesting again for the fleet managers.

Afterwards, within the proposed methodology for the energy efficiency improvement onboard the ships in service the determined methods will be applied as presented in the table no. 2.

3. The energy efficiency computation for the identified methods onboard the operating ships

In order to determine the level of the ship energy efficiency both for the initial situation and for the proposed scenarios, the recommended method by the IMO's in MEPC 212(63) decision has been used [7].

As known:

$$EEDI_{ship} = \frac{\sum_{k=0}^{n} m_{CO2\ MP} + \sum_{k=0}^{n} m_{CO2\ MA}}{b_{max} * V_{max\ ref}} \quad [g_{CO2}/t/mile] \quad (2)$$

where: $m_{CO2\ MP}$ - CO_2 emissions mass as exhausted by the propulsion engine;

$\sum_{k=0}^{n} m_{CO2\ MA}$ – the sum of CO_2 mass of emissions exhausted by the diesel generators;

b_{max}- maximum displacement of the ship;

$V_{max\ ref}$ – referential speed of the ship.

Table 2

Measures	Energy saving rate (α)
Speed reduction by 10%	15%
Speed reduction by 20%	36%
B20 mixture usage on the maximum nominal speed	Depending on the engine load
B20 mixture usage on the speed reduction by 10%	Depending on the engine load

To determine the mass of the CO_2 emissions from diesel engines' exhausting gases, the formula determined by the stoichiometric burning equation has been used [3,4]:

$$m_{CO2} = 3,666 * c * FOC \quad [g_{CO2}/h] \quad (3)$$

where: FOC – hourly fuel consumption [kg_{comb}/h];

c – carbon concentration in the fuel [%].

In case of using the method of replacing the naval classic fuels with the 20% biodiesel mixture (B_{20}), the real B_{20} consumption will not be precisely known. Therefore, the mass computation for the CO_2 emissions, in case of exhausting gases coming from diesel engines, will take into account the CO_2 mass for the classic fuels, but in ratio with the engine load as following:

$$m_{CO2\ B20} = m_{CO2\ diesel} \cdot (1 - y) \quad [g_{CO2}/h] \quad (4)$$

where: $y = -579{,}8 \cdot LF^3 + 917{,}1 \cdot LF^2 - 363{,}2 \cdot LF + 26{,}15$ [%]; $m_{CO2\ diesel}$ – the mass of CO_2 determined in case of classic fuels in maximum engine load; LF- loading factor for the engine [%]. [3]

In case of the propulsion engines, the LF as presented in table 8 has been calculate depending on the ship speed, and in the case of secondary engines, depending on the loading burden for the generators [8].

(6.1)

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Table 3

Viteza navei (%)	Factor de încărcare LF_{MP} (%)	Consum orar de comb.(%)
100%	75%	100%
90%	55%	73%
80%	38%	52%

Based on the formulas (2), (3), respectively (4) $EEDI_{ship}$ will be calculated for each method applied onboard and further proposed in the study.

4. The real costs computation for implementing the identified measures onboard the ships in service

The effective cost to implement onboard the operating ships each analysed managerial measure is reflected by the marginal cost of the final reduction, computed based on the next formula [10]:

$$MAC = \frac{\Delta C_j}{\alpha_j \times CO_2} = \frac{K_j + S_j - E_j + \sum O_j}{\alpha \times CO_2} \quad (5)$$

where :

ΔC_j = capital cost;

K_j = ΔCj the capital cost updated on the interest rate and the years in service;

S_j = the effective cost to implement the managerial measure;

$\sum O_j$ = the opportunity costs, related to the additional time recorded in order to implement the energy saving measure and the value of the saved capital alternative usage;

E_j = energy savings value, calculated as the product between the saved energy and the price of energy per unit;

α_j = the discount rate for energy savings applying the identified measure j;

CO_2 = ship's CO_2 emissions before applying the identified measure.

4.1. The MAC value computation in case of ship's speed reduction scenario by 10%

Reducing the ship's speed by 10% the fuel consumption for the propulsion engine will further decrease by 27% (see table 1), but the number of the voyage will increase, determining consequently the boost of the yearly consumption for the auxiliary engines. Also together with it, the yearly consumption of the donkey boiler will increase, as required for the fuel heating operations. Moreover, recording an increment for the sailing days will further record losses in total freight cashed as price for the transportation services due to a slower dynamics. Afterwards, the marginal cost in case of the stated scenario shall be defined as following:

$$MAC_1 = \frac{\Delta C_1}{\alpha_1 \cdot CO_2} = \frac{S_1 - E_1 + O_1}{15\% \cdot CO_2} \quad [\$] \quad (6)$$

where:

α_1 – the reduction percentage using the stated method;

S_1 – represents the value of the fuel consumption as used in addition by the diesel generators and the value of fuel used in addition by the donkey boiler for the additional yearly sailing days using the stated method;

O_1 – the additional cost recorded together with the delay scored because of the speed reduction by 10%;

E_1 – the main engine yearly consumption saved by implementing the stated method;

CO_2 – the mass of CO_2 emissions exhausted initially by the ship.

Consequently:

$$S_1 = (C_{MA\ mas1} - C_{MA\ ref}) + (C_{boiler\ mas1} - C_{boiler\ ref}) \quad (7)$$

$$O_1 = (N_1 - N_{ref}) \cdot C_v \quad [\$] \quad (8)$$

$$E_1 = (C_{MP\ mas\ 1} - C_{MP}) \quad [\$] \quad (9)$$

where:

$C_{MA\ mas1}$ – the cost of yearly fuel consumption of the auxiliary engines in case of the stated method implementation;

$C_{boiler\ ref}$ – the cost of the yearly fuel consumption of the donkey boiler on the rated speed;

$C_{boiler\ mas1}$ – the cost of the yearly consumption for the donkey boiler, in scenario of speed reduction by 10%;

$C_{annual\ MP}$ – the annual cost of the fuel used by the propulsion engine on the nominal speed of the ship [kg comb/hour];

$C_{annual\ MP\ mas1}$ – the annual cost of the fuel used by the propulsion engine on the reduced speed by 10% [kg comb/hour].

C_v – the average rate freight for a day of voyage [$];

N_1 – number of the sailing days when implementing the method;

N_{ref} – number of sailing days before applying the method.

4.2. The MAC value computation in case of ship's speed reduction scenario by 20%

In case of implementing this scenario, the fuel consumption for the propulsion engine will decrease by around 48%, but the number of sailing days will increase determining a boost in the annual consumption of the auxiliary engines together with the increment in functioning period.

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Once implemented the consumption for the boiler will also increase prolonging the required timing for heating the fuel. Moreover, together with the sailing days extension a significant decrease in the profit will be recorded, in ratio with the additional delay in contract fulfilment.

Afterwards, the marginal cost for the stated method implementation could be defined as following:

$$MAC_2 = \frac{\Delta C_2}{\alpha_2 \cdot CO_2} = \frac{S_2 - E_2 + O_2}{36\% \cdot CO_2} \quad [\$] \tag{10}$$

where:
α_2 – the reduction percentage for the fuel consumption implementing the stated method;
S_2 – the value of the fuel used by the diesel generators and the value of the fuel used by the boiler for the additional sailing days, implementing the stated method;
O_2 – the cost of recorded delay implementing the measure of reducing the speed by 20%;
E_2 – the value of the saved fuel on annual basis, implementing the stated method.

Beside this,

$$S_2 = (C_{MA\ mas2} - C_{MA\ ref}) + (C_{boiler\ mas2} - C_{boiler\ ref}) \quad [\$] \tag{11}$$

$$O_2 = (N_2 - N) * C_V \quad [\$] \tag{12}$$

$$E_2 = \left(C_{MP\ mas\ 2} - C_{MP}\right) \quad [\$] \tag{13}$$

where:
$C_{MA\ mas2}$ – the cost of the annually fuel consumption for the auxiliary engines in case of method implementation;
$C_{boiler\ mas\ 2}$ – the cost of the fuel yearly consumption for the donkey boiler, in case of reducing the speed by 20%;
$C_{annual\ MP\ mas2}$ – the annual cost of the fuel used by the propulsion engine, on the reduced speed by 10% [kg comb/hour];
N_2 – the number of the sailing days in case of method implementation.

4.3. The MAC value computation in case of B20 usage on the maximum baseline speed

In case of using the naval engines with alternative fuels based on B_{20} mixtures the annual consumption of the main engine will decrease. On the other hand, in this scenario is no longer need for heating the fuel so the consumption with the boiler will also decrease. In this case, the marginal cost of the implemented method will be determined based on the following formula:

$$MAC_3 = \frac{\Delta C_3}{\alpha_{B20} \cdot CO_2} = \frac{O_3 - E_3}{m_{3\,CO2}} \tag{14}$$

where:
O_3 – is the value of the cost difference between the main engine annual consumption and the auxiliary engines consumption in case of using either the B_{20} mixture or the classic fuels;
E_3 – the value of the saved fuel on annually basis for implementing the stated method;
m_{3CO2} – the mass of CO_2 emissions exhausted by the engines fuelled with B20 mixture, that will be determined based on formula (4).
And:

$$O_3 = (C_{MP\ B20} - C_{MP}) + (C_{MA\ B20} - C_{MA}) \; [\$] \tag{15}$$

$$E_3 = C_{cald\ ref} \quad [\$] \tag{16}$$

where:
$C_{MP\ B20}$ – the annual cost of the propulsion engine fuelled with B_{20} mixture;
$C_{MA\ B20}$ – the annual cost of the auxiliary engines fuelled with B_{20} mixture;
$C_{cald\ ref}$ – the value of the fuel saving because of not using the boiler for fuel heating.

4.4. The MAC value computation in case of B20 usage on the reduced speed by 10% in ratio with the baseline speed

In case of using the alternative fuels based on B_{20} mixtures to feed the naval engines together with the speed reduction by 10%, the annual consumption of the main engine will decrease based on slow steaming principle. On the other hand, in this scenario the fuel heating is no longer required so the consumption with the boiler will also decrease. Because the delay recorded sailing with slower speed, the profit sill also decrease consequently. In this case, the marginal cost of the implemented method will be determined based on the following formula:

$$MAC_4 = \frac{\Delta C_4}{\alpha_{B20} \cdot CO_2} = \frac{O_4 + S_4 - E_4}{m_{4\,CO2}} \tag{17}$$

where:
S_4 – the value of the diesel generators' fuel consumption for the additional sailing days, counted as delay implementing this method;
E_4 – the value of the fuel saved on annually basis implementing this method together with the value of the saved fuel for not using the boiler;
O_4 – the cost for recorded delay, when speed reduced by 10%.
Iar:

$$S_4 = (C_{annual\ MA4\ B20} - C_{annual\ MA}) \quad [\$] \tag{18}$$

$$E_4 = (C_{annual\ MP4\ B20} - C_{annual\ MP}) + C_{boiler\ ref} \quad [\$] \tag{19}$$

$$O_4 = \left(N_4 - N\right) \cdot C_V \quad [\$] \tag{20}$$

where:
$C_{annual\ MA4\ B20}$ – the annual cost for fuelling the auxiliary engines with B20 mixture on a speed decreased by 10%;

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$C_{annual\ MP4\ B20}$ – the annual cost for fuelling the main engines with B20 mixture on a speed decreased by 10%

N_4 – the number of sailing days, when implementing the method. $N_4 = N_1$.

5. The decision making process for selecting and implementing the optimum method to improve the energy efficiency onboard the ships

In order to analyse the proposed methods within the methodology, the next cost-benefit variables should be priory considered, as major restriction of the decision making process:

- The energy efficiency coefficient should be lower than the IMO enforced limit:

$$EEDI_{ship} < EEDI_{IMO} \tag{21}$$

- The marginal cost of the implemented method should be negative not to affect the maritime transports profitability:

$$MAC_{method} < 0 \tag{22}$$

The decision regarding the optimum method to be implemented for energy efficiency onboard the ship, should consider the cost-benefit analysis, checking if the next conditions are fulfilled by the tested method "i" in ratio with the following proposed method "j" :

$$EEDI_{method\ i} < EEDI_{method\ j} \tag{23}$$

and

$$MAC_{method\ i} < MAC_{method\ j} \tag{24}$$

On the other hand, the decision is taking into account two major factors, according to the presented formulas (6), (10), (14) și (17), namely:

- the price for fuel;
- freight rate market.

The price for fuel

The price for fuel is the most significant variable to determine the marginal cost to reduce the mass of CO_2 emissions, mainly because the fuel cost represents up to 60% out of the total ship operation costs.

Nowadays, in spite of the fact that the tendency of the fuel price use to be on ascended trend, we do not have an updated forecast on medium or long run for the oil price. Moreover the uncertainty is increased by the higher probability of introducing the environment fares in the fuel price, to stimulate the ships' emissions limitation.

To comply with this complexity of the market evolutions, within the proposed methodology 3 scenarios were taken into account to cover the uncertainty regarding the prices for naval fuels foreseen for 2020, as following:

- *The minimum scenario* has been designed considering the last oil price forecast for 2020 by 77$ as issued by EIA (Energy International Agency) [13], correlated with the relation between the oil price and the prices for classic naval fuels, calculated in ratio with the yearly recorded average for 2016 [15].

Figure 1. Annual Energy Outlook 2016 [15]

- *The medium scenario* has been designed similarly adding in the price for HFO/tonne a fare of 30% for sulphur, citing the estimations from the consulted literature [11,12].
- *The maximum scenario* is the mean alternative, when a carbon fare of 45$/tonne has been added for HFO and a fare of 25$/tonne has been added for diluted fuels (MGO, MDO) [14].

Regarding the B_{20} fuel mixture price quotation for 2020, the work hypothesis took under consideration the actual quotation for biodiesel of 830$/tonne [16], foreseen to be kept on the same level by 2020. Because at the moment there is no reliable price quotation for B_{20} mixture in naval fuels, its price will be hypothetically compounded as 20% from the biodiesel price rate and 80% from naval classic fuel rate. Hence, the naval fuel quotations for 2020 used in the methodology, for all three scenarios are presented in table 4.

Table 4

Scenarios	IFO 380	IFO 180	MGO	MDO	B20
Minimum scenario (USD/tonne)	580	620	1100	1050	1025
Average scenario (USD/tonne)	750	800	1100	1050	1025
Maximum scenario (USD/tonne)	800	850	1125	1075	1025

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Freight rate market
The daily spot freight rate is one of the most relevant cost component, when the opportunity cost is determined applying energy efficiency. In this respect the sport freight rate is used to compute the losses recorded from delays when slow steaming is accepted as solution for energy efficiency achievement. Because the freight rate is determined by a wide range of variables (e.g. type of cargo, sort of goods, route for navigation) the final value used in the managerial analysis methodology will be computed as linear mean of the freight rates cashed in the reported period.

CONCLUSIONS

The proposed methodology is suitable for the older ships, longer than 10 years in operation, for which were priory identified several managerial methods with an effective and efficient effect against the mass of CO_2 emissions, targeting to align the propelling systems to the upcoming IMO standards, as solution to keep these transport units still in function for several more years. The major contribution brought in this article is related to the identification of most significant managerial methods with a significant impact in the environmental policies.
Once these methods identified, analysed and prioritized as depicted in the present paperwork, in order to optimize the decision making process, the authors have further developed an Microsoft Excel computing tool for the sake of an efficient operational ship management. In the program the methods and restrictions have been introduced as to calculate, depending on the engine types and the ship particularities, the algorithm to be applied by the operational management, in considering the most efficient method priority, in order to reduce the mass of CO_2 emission exhausted by the ship equipments.
This program, together with the whole set of presented indicators shall be a proper instrument in the future to support the management in continuing to operate the old ships, but in fully accordance to the IMO standards for a sustainable development of the maritime business worldwide.

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