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Investigation Slow Steaming for Container Ships Using Speed and Power Estimation in Indonesian Water

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ABSTRACT

Indonesia, which is an archipelagic country, really needs sea transportation as a necessity for efficient delivery of materials. Delivery of goods is carried out using container ships as the main means. The impact of this shipping is mainly an increase in fuel consumption which causes pollution and a decrease in profits for ship owners. The practice of using slow steaming is widely used in maritime transportation. This research will provide a summary of the use of slow steaming to obtain fuel efficiency and benefits in ship operations. A case study was carried out on the Surabaya - Jakarta - Kabil Indonesia shipping route. Calculation of the effect of fuel uses speed parameters to provide a good economic effect and on the environment. The use of this method also shows the potential for cost savings with optimal ship speed which can reduce fuel consumption. Several variables determined during container ship operations will be used to determine speed optimization using the Slow Steaming method. The results of this case study can be used as a reference in determining the economic and environmental benefits of implementing slow steaming, as well as being a method for energy-saving device initiatives.

1. Introduction

Ships are a mode of sea transportation that functions as a tool for distributing goods or commodities from one place to another. This transportation process certainly has economic and environmental processes that need to be considered in its operations. The economic process is related to shipping operating costs or voyage costs which include the costs of fuel, clean water, and crew needs. The largest cost component is influenced by fuel costs. If we look further, fuel consumption is influenced by speed, hull shape and ship engines. The shape of the hull makes a significant contribution to the influence of resistance which results in reduced engine work efficiency, thereby increasing fuel costs. World governments support efficiency and reduction of marine pollution or excess carbon dioxide (CO_2) emissions due to sea transportation modes. Ships contributed 2.2% of emissions on earth in 2012 which is predicted to continue to increase to 250%

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in 2050 if efforts are not made to increase efficiency and reduce emissions [1]. The concept for energy efficiency is shown in Figure 1.

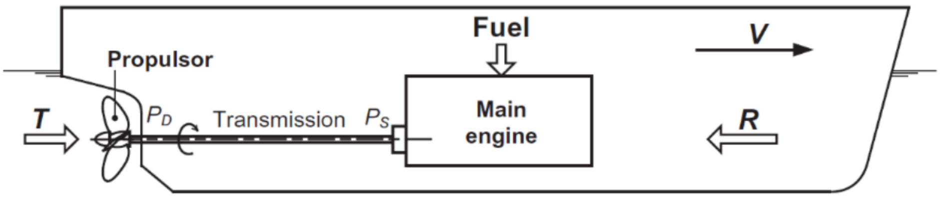

Fig. 1. Efficiency energy concepts [2]

The problem of increasing fuel consumption can become an environmental problem by increasing carbon emissions in the air. The continuous large-scale fuel consumption factor causes this impact to continue. Efforts to reduce fuel consumption have been offered in several stages by IMO. One effort to reduce this is to increase energy efficiency when ships are sailing. This can be achieved by paying attention to the influence of wind, water depth and current speed when the ship is operating [3,4]. Choosing the right current by considering shipping lanes and winds can significantly increase the impact of energy efficiency [5].

The government, non-governmental organizations and shipping companies have taken a role and are trying to improve energy efficiency [6]. Energy efficiency will reduce fuel consumption which will indirectly reduce exhaust emissions on ships. The fuel consumed by a ship is influenced by the performance of the main engine on the ship. Optimizing ship operations is an alternative for increasing fuel efficiency [7]. Determination of fuel consumption has been designed before determining engine power. This is done by calculating the resistance coefficient of the ship in calm water conditions when the ship was designed. This process will influence the values and coefficients which are directly correlated with the characteristics of the structure and shape of the ship's hull, so that they differ from one region to another. The structure and shape of the ship's hull will affect the value of the ship's hydrostatics, so this variation will affect the ship's hull consumption. Efforts to improve shipping are carried out by implementing slow steaming and weather routing [5]. Which is an operational process carried out by cargo ships, especially containers, which significantly reduces speed during the shipping process to save fuel consumption. Proven in 2010, Wartsila calculated a fuel reduction of 59% from cargo ships when reducing service speed, namely from 27 knots to 18 knots [8].

IMO in the GloMEEP Project 2018 [9], added that to support energy efficiency in shipping transportation, it also carries out smart steaming which is studied during operational time to obtain data. Smart steaming has various benefits, namely reducing fuel consumption by 30%, and reducing costs and exhaust emissions [10]. Of course, in implementing this concept, an adequate control system is needed on the ship and the application of multiple objective optimization techniques is needed to response to changing conditions, including weather, sea state, and port status [11]. Communication between stakeholders also needs to be improved between ship operators, ship owners, ports, and consumers who use shipping services. This operational process enters the internal stage which influences fuel consumption. In this research, slow steaming analysis was carried out according to speed data by considering the comparison of fuel consumption in a ship operation in the container ship case study.

2. Methodology

This research was conducted to understand fuel consumption from the perspective of improving energy efficiency on ships. This study of the application of slow steaming is an interesting material for increasing efficiency in ship operations. In this research, the slow-steaming application from shipping industries uses data on container ships operating in Indonesian waters. Container ships are a type of commercial ship specifically designed to carry container cargo, increase loading and unloading efficiency, and deliver goods properly. So, this ship is crucial and essential in sending goods between countries at lower costs.

The shipping in this analysis starts from Tanjung Perak Harbor, Surabaya, to Kabil Harbor via the Jakarta Port route. The observation became interesting after it was discovered that the ship's main engine was operated using a slow-steaming model. In other words, the use of this method can make a significant contribution to ship operations. The stages are focused on data processing and the operating principles of slow steaming on ships by proving the relationship between speed and fuel consumption.

Further investigation into the relationship between speed and fuel consumption is necessary. Power, speed, and fuel consumption are correlated, and in several studies, this correlation can reduce emissions or greenhouse gases (GHG). So that identification can be carried out as consideration in supporting regulations. The IMO strategy to reduce fuel consumption is assumed to be reducing speed. This effect correlates with a non-linear or exponential decrease in GHGs with speed [12].

The studies conducted show that the application of traditional cases or "propeller law" has proven to be less accurate in determining correlation. The estimating using cube laws or hydrodynamic principles is something that is possible but takes a long time. Referring to research developed by Salvesen *et al.,* [13], determining overall speed vs power uses attention to calm water conditions which are then developed with wavy waters, this increases resistance exponentially. Estimation of additional drag is a complex process, generally depending on the shape of the ship's hull, the hydrodynamic characteristics of the ship, and environmental conditions that can be determined by strip theory.

Then, assumptions that are widely used in shipping engineering use hydrodynamic principles to determine the correlation between ship power requirements and ship speed which can be estimated using Eq. (1).

$$P(v) = kv^3 \tag{1}$$

Where v is the internal speed (knots) and P(v) is the power requirement, including main engines, boilers, and auxiliary engines (kW) and k is a constant. The formula can be further improved to Eq. (2).

$$P(v, w) = m(A + w)^{\frac{2}{3}}v^n \tag{2}$$

Where w is the ship's payload, A is the ship's weight, n is the exponent, where if ≥ 3 and m is another constant. The above equation was modified, so that the power is 2/3 of the ship's displacement so that the fact is $\Delta^{\frac{2}{3}}$ or according to the wetted area of the ship's hull. The exponent of speed or in this equation is n cannot be calculated if it is obtained less than 3, in still water resistance R_T the drag function C_T, the water density is ρ, the speed is v, and the submerged area is S, is formulated as Eq. (3).

$$R_T = (1/2)\rho C_T v^2 S \tag{3}$$

C_T is obtained from C_F and C_R, both of which are quadratic functions of the speed in the water (v). C_F is indirectly influenced by ship size. where in wavy water conditions the speed can be twice the square or v^4 [14]. This means that the water resistance value cannot have a value below 2. The best case is where the ship has low speed and low residual resistance. It can be calculated using Eq. (4).

$$\mathrm{P} = \mathrm{v}R_T = (1/2)\rho C_T v^2 S \tag{4}$$

These results will show the power requirements for fuel consumption, by multiplying the specific power requirements by knowing the SFOCs which are generally not constant with speed changes and depend on engine characteristics and engine propeller matching.

In this study, the calculation focusses on the emission produced by the main engine. Carbon emission will be calculated as following approach of Eq. (5) [15].

$$\left\{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} C_{FME(i)} SFC_{ME(i)}\right)\right\} \tag{5}$$

Where CFME is the conversion factor fuel oil to CO_2 and depends on the fuel type documented in the NOx Technical File, which for diesel/gas oil, are 3,206 [19]. SFCme is the specific fuel consumption of the main engine at 75% MCR. fj is the correction factor for ship specific design elements which if no ship specific design elements are installed, the factor is set to 1. PME could be obtained using following Eq. (6) [15].

$$\mathrm{PME(i)} = 75\% \ (\mathrm{MCR(i)} - \mathrm{PPTO}) \tag{6}$$

Which the MCR (The maximum continuous rated power output) is as specified in the Technical File of the marine diesel engine. To estimate the EEDI, following equation could be conducted.

$$EDI = \frac{CO^2 Emission}{Transport\ work} \tag{7}$$

$$EEDI = \frac{P_{ME(i)} C_{FME(i)} SFC_{ME(i)}}{C\ v} \tag{8}$$

Where C is the capacity and v are the speed of the ship.

3. Results

3.1 Effect Ship Speed in Oil Consumption

For shipping companies, the main reason for using slow steaming is to reduce fuel consumption during engine combustion. Ship operations not only consume fuel, but also lubrication and combustion used in auxiliary engines when the ship is anchored. In this research, the effect of fuel consumption will be calculated using the price assumptions used [16]. With the route used, fuel usage optimization will be obtained [17]. Therefore, these expenses can be reduced. The recognition of the potential for fuel reduction is widely explained but not specified in detail because it is too complex, with this simplification a virtual explanation will be obtained which is presented in Figure 2 in this case study [18]. Based on the characteristics of the container ship data used, the following shows the potential for fuel savings on container ships with a function of fuel consumption versus speed. Two lines show the nearest function line followed by a polynomial function.

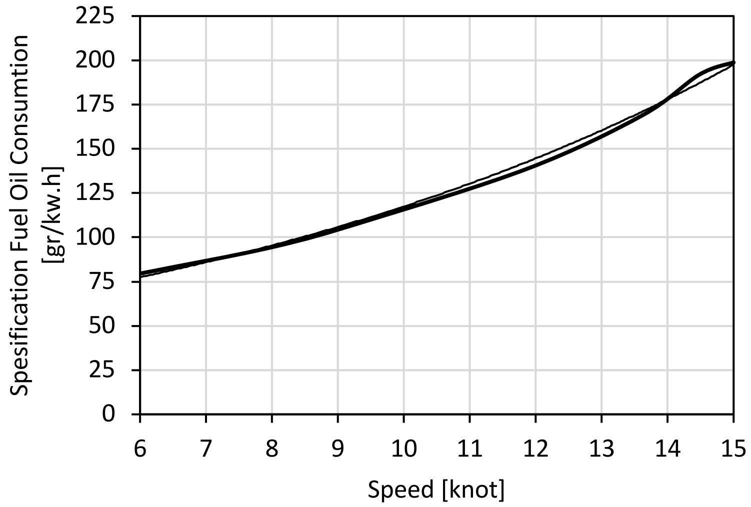

Fig. 2. Fuel consumption as function of ship speed.

As an example in the data that is provided in Table 1, a container ship on a trip from Surabaya to Jakarta and heading to Kabil that uses slow steaming is estimated to save approximately 17.88 tons of fuel consumption, and that financial accountings of 12,500 $ per trip.

Table 1
Data used for input calculation of fuel consumption

Parameter	Value, unit
Distance	1670 nm
Fuel Price	699 $/tons
Vessel Speed (Normal)	15 kN
Vessel Speed (Slow Steaming	9.44 kN

Apart from fuel consumption costs, it also affects the consumption of lubricating oil burned in the engine. This consumption is also a factor in increasing the cost of fuel used. The speed function is also influential because it is directly proportional to the power produced by the engine. Furthermore, the input data used to determine lubricating oil consumption for specific fuel consumption can be seen in Figure 2 where if the speed increases it will affect fuel consumption. The maximum SFOC value for the main engine is 198.8 gr/kWh and for Specific Lubricating Oil consumption it is 0.8 gr/kWh and the price of lubricating oil per ton is 4,950 $/t.

Another effect of reducing fuel consumption due to slow steaming is a reduction in several emissions. When fuel combustion decreases, this causes the amount of carbon dioxide (CO_2) and sulfur (SOx) to decrease, so this is considered positive because apart from getting efficient use of fuel, ship owners also support the IMO program by reducing emissions.

3.2 Effect Slow Steaming in Ship Operational

The effect of slow steaming on ship operations will be seen in the length of the voyage during its operational implementation. The maximum number of round trips for one year can be calculated by considering the effective cargo value carried with a constant value of 0.87 times the number of TEUs transported. The total operational time for one year will be divided by the full time taken for one trip, obtained from the length of sailing time and the time berthed at the port. The known port distance and travel time at each speed are shown in Table 2.

Table 2
Data used to determine operational cost

Ship Speed (knots)	Sail Time (hours) SUB-JKT 386 nm	JKT-KBL 523 nm	KBL-SUB 761 nm
6	64.00	87	120.7
8	48.00	65	95
9.44	41.00	48.7	72.9
11.9	24.08	44	64
13.62	24.40	38	48.8
14.48	24.30	36	48.5
15	24.20	35	48.3

The length of stay at Jakarta, Surabaya, and Kabil ports is 52 hours, 68 hours, and 65.5 hours, respectively. Anchoring fees in Indonesia must be prepared anchor services, pilot services, tugboat services, and mooring. Also, Table 2 will affect anchoring costs, especially for mooring services, calculated per GT/etmal, which means etmal is equal to 24 hours. Each of these costs is calculated and the total costs per anchor are presented in Table 3.

Table 3
Port services facilities cost

Port Cost ($)	Surabaya	Jakarta	Kabil
Anchorage Services	227.5	175.06	171.08
Pilot Services	244.35	244.34	136.57
Tugboat Services	389.44	389.43	145.61
Mooring Services	83.55	125.33	86.43
Total	944.83	934.17	539.68

Then, in determining crew and provision costs in this calculation, the state is approximately 1,250 $/h. More details describing the length of sailing time versus time and fuel consumption are presented in Figure 3.

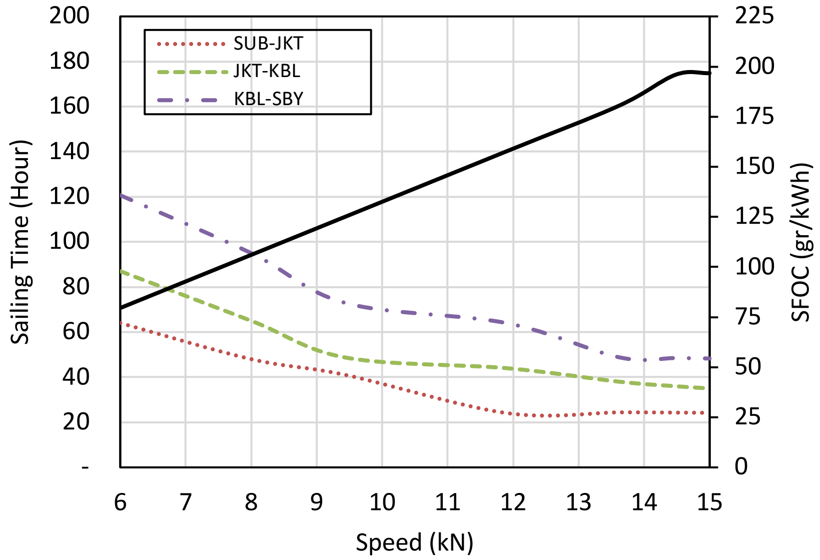

Fig. 3. Sailing time in each ship routes

This relationship shows that if the speed is increased, the sailing time will decrease, but it should be noted in the speed vs SFOC graph that at a data speed of 9 knots the increase in the curve is extreme so that in these conditions it will require a lot of fuel so slow steaming can be carried out at speeds between 6 knots up to 9.44 knots as used in this case study. In this analysis, the cargo price per voyage carrying the maximum load is 537.66 TEUs. However, the operational costs of one cruise can be calculated for one trip, and the price can be projected for one year. With the cost of one container shipping, the net profit is $1100.

3.3 Effect of Slow Steaming in EEDI

In his analysis, fuel consumption and energy efficiency are important aspects in maritime operations, which directly affect operational costs and environmental sustainability [19]. The use of slow steaming is to comprehensively analyze how much fuel consumption and carbon emissions are produced so that we can find out the impact of using slow steaming on the emissions produced. Indirectly, this proves that by running at eco speed or slow steaming, apart from benefiting from fuel savings, it can also support a sustainable environmental impact by reducing the level of carbon emissions per hour [20]. The results of the EEDI calculation are presented in Figure 4 and in more detail in Table 4.

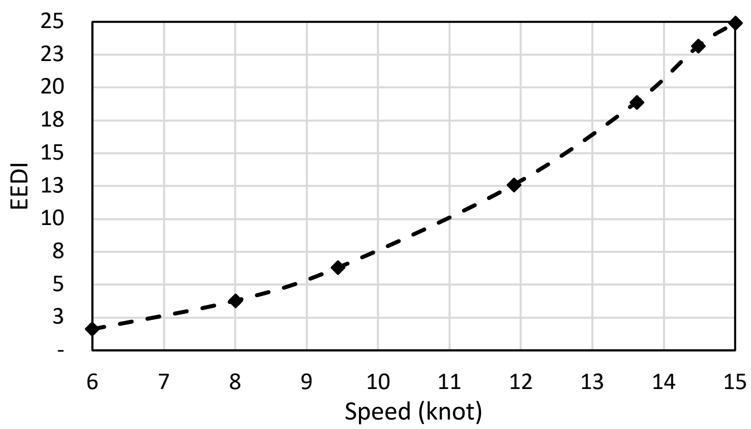

Fig. 4. EEDI for each operation speed

Furthermore, it is noted that a decrease in sailing speed is accompanied by a decline in carbon emissions, generate the same trend as fuel cost. This mirrors the theory behind slow steaming, suggesting that intentional reduction in speed serves as a method to mitigate the environmental impact by lowering carbon emissions. This trend aligns with the broader goal of achieving enhanced energy efficiency in maritime activities, as reflected in the EEDI. The slowest speed analyzed 6 kN, generate the lowest EEDI generated which reach 75% decrease compared to the existing maximum ship speed. As sailing speeds decrease contributing to an eco-friendlier operation, there is a consequential alignment with the principles of EEDI, illustrating a positive correlation between reduced speeds, lower carbon emissions, and improved energy efficiency standards.

Table 4
EEDI for each operation speed

Speed (kN)	Carbon Emission (g/H)	EEDI
6.00	54,679	1.61
8.00	170,872	3.78
9.44	336,048	6.30
11.90	847,241	12.60
13.62	1,454,548	18.90
14.48	1,894,269	23.15
15.00	2,113,338	24.93

Hence, we can see a significant difference in the application of slow steaming and normal speed, where slow steaming is technically calculated to reduce carbon emissions and reduce EEDI figures that, in this case, support the IMO program to create zero carbon emissions and a sustainable environment [21, 22].

3.4 Effect of Slow Steaming in Profit

Catching the large difference in fuel consumption is certainly not a secret in the operational strategy of slow-steaming ships being chosen as a unique and effective alternative for gaining fuel efficiency. This scheme certainly requires deeper analysis, especially as ship operational correlation considers many factors. The parameters that are taken into consideration in this case are the size of the ship, which is reduced to the effective volume of cargo carried, the condition of the propulsion engine, fuel consumption, and shipping distance, which are formulated into four basic operating costs. The cost segmentation that has been added up is reduced to gross profit so that the net profit generated within one voyage can be obtained. In this case, the projection of the resulting profit is carried out by looking at the optimal speed to be used during the time the ship is sailing. The results of calculating the operating profit for one year show that 23 effective trips can be made; a picture of the operating profit for one year can be seen in Figure 5.

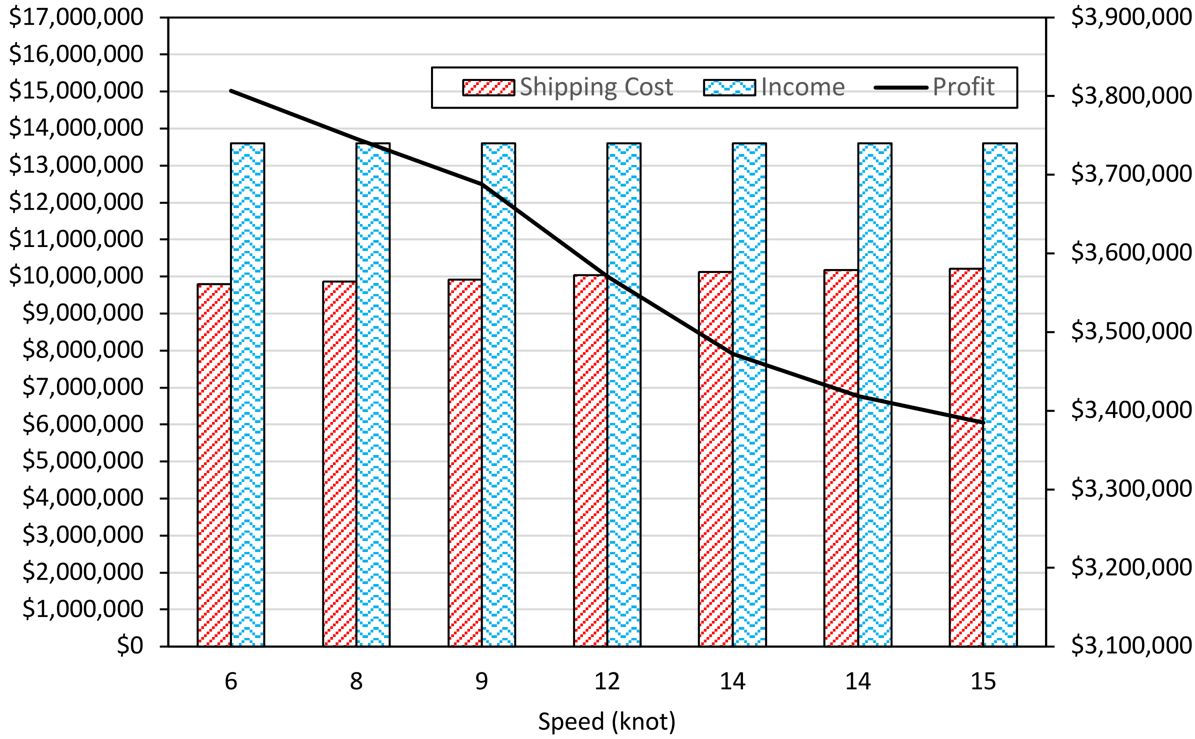

Fig. 5. Income, shipping cost, and profit as function of container ship speed

Figure 5, in detail, explains that the significant decrease in profit starts at a speed of 9 - 15 knots, and at a speed of 6 - 9 knots, the speed of the profit graph tends to be gentle and does not decrease drastically. Thus, the selection of effective speed in determining the most appropriate profit is applied to slow steaming speeds in the range of 6-9 knots. The ideal operational speed chosen in this case study is 9.44 knots. With a large difference between using speeds of 15 knots and 9 knots, it results in a profit difference of 7.95% or $302,786.93; of course, this is very important because the time difference is not too considerable but can result in quite high savings and increased profits.

4. Conclusions

Therefore, this case study describes the use of slow steaming in Indonesia and the resulting income, shipping costs, and profits. Based on the results of the analysis of the case study, it was found that the optimal speed used for slow steaming, which is suitable for Surabaya - Jakarta - Kabil shipping, is 9.44 knots. These results are supported by evidence of an efficient reduction in fuel consumption and a reduction in EEDI in ship operational processes. Of course, this study needs to be improved by looking at variations in ship size and ship engine conditions in the future to obtain data with sufficient accuracy.

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References

[1] Mallouppas, George, and Elias Ar Yfantis. "Decarbonization in shipping industry: A review of research, technology development, and innovation proposals." Journal of Marine Science and Engineering 9, no. 4 (2021): 415. https://doi.org/10.3390/jmse9040415
[2] Molland, Anthony F., Stephen R. Turnock, and Dominic A. Hudson. Ship resistance and propulsion. Cambridge university press, 2017. https://doi.org/10.1017/9781316494196
[3] Ariani, Betty, Rizky Chandra Ariesta, Ahmad Wildani, M. Hanifuddin Hakim, and Marista Oktaviani. "Ship performance investigation due to deadrise modification: A case study passenger ship." Journal of Applied Engineering Science 21, no. 2 (2023): 608-617. https://doi.org/10.5937/jaes0-41234
[4] Ariesta, R. C., M. H. N. Aliffrananda, S. Riyadi, and I. K. A. P. Utama. "An investigation into the justification of the service speed of ro-ro ferry with block coefficient 0.8 based on the resistance and seakeeping performance." In 7th International Conference on Ship and Offshore Technology, ICSOT Indonesia 2021, pp. 113-122. Royal Institution of Naval Architects, 2021. https://doi.org/10.3940/rina.icsotindonesia.2021.15
[5] Rehmatulla, Nishatabbas, John Calleya, and Tristan Smith. "The implementation of technical energy efficiency and CO_2 emission reduction measures in shipping." Ocean engineering 139 (2017): 184-197. https://doi.org/10.1016/j.oceaneng.2017.04.029
[6] Farag, Yasser BA, and Aykut I. Ölçer. "The development of a ship performance model in varying operating conditions based on ANN and regression techniques." Ocean Engineering 198 (2020): 106972. https://doi.org/10.1016/j.oceaneng.2020.106972
[7] Goicoechea, Nestor, and Luis María Abadie. "Optimal slow steaming speed for container ships under the EU emission trading system." Energies 14, no. 22 (2021): 7487. https://doi.org/10.3390/en14227487
[8] Wiesmann, Andreas. "Slow steaming–a viable long-term option." Wartsila Technical Journal 2 (2010): 49-55.
[9] GloMEEP. "Speed Management." (2012).
[10] Dere, Caglar, Burak Zincir, Omer Berkehan Inal, and Cengiz Deniz. "Investigation of the adverse effects of slow steaming operations for ships." Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment 236, no. 4 (2022): 1069-1081. https://doi.org/10.1177/14750902221074191
[11] Lee, Habin, Nursen Aydin, Youngseok Choi, Saowanit Lekhavat, and Zahir Irani. "A decision support system for vessel speed decision in maritime logistics using weather archive big data." Computers & Operations Research 98 (2018): 330-342. https://doi.org/10.1016/j.cor.2017.06.005
[12] TOKUŞLU, Aydın. "Analyzing the Energy Efficiency Design Index (EEDI) performance of a container ship." International Journal of Environment and Geoinformatics 7, no. 2 (2020): 114-119. https://doi.org/10.30897/ijegeo.703255
[13] Salvesen, Nils, E. O. Tuck, and Odd Faltinsen. "Ship motions and sea loads." (1970).
[14] Schneekluth, Herbert, and Volker Bertram. Ship design for efficiency and economy. Butterworth Heinemann, 1998.
[15] Molland, A. F., S. R. Turnock, D. A. Hudson, and I. K. A. P. Utama. "Reducing ship emissions: a review of potential practical improvements in the propulsive efficiency of future ships." International journal of maritime engineering 156, no. A2 (2014). https://doi.org/10.3940/rina.ijme.2014.a2.289
[16] Wulandari, Amalia Ika, I. Utama, Afifah Rofidayanti, and Dominic Hudson. "Numerical analysis of ship motion of crew boat with variations of wave period on ship operational speed." CFD Letters 16, no. 4 (2024). https://doi.org/10.37934/cfdl.16.4.115
[17] Meyer, Jasper, Robert Stahlbock, and Stefan Voß. "Slow steaming in container shipping." In 2012 45th Hawaii International Conference on System Sciences, pp. 1306-1314. IEEE, 2012. https://doi.org/10.1109/HICSS.2012.529
[18] Setiawan, Wira, Amalia Ika Wulandari, Aditya Miftahul Huda, and Syerly Klara. "Comparative Study of Ship Resistance and Fuel Consumption between Axe Bow and Moor Deep Ram Bow using CFD Method." CFD Letters 14, no. 8 (2022): 71-80. https://doi.org/10.37934/cfdl.14.8.7180
[19] Wu, Wei-Ming. "The optimal speed in container shipping: Theory and empirical evidence." Transportation Research Part E: Logistics and Transportation Review 136 (2020): 101903. https://doi.org/10.1016/j.tre.2020.101903
[20] Sou, Weng Sut, Tian Goh, Xin Ni Lee, Szu Hui Ng, and Kah-Hin Chai. "Reducing the carbon intensity of international shipping–The impact of energy efficiency measures." Energy Policy 170 (2022): 113239. https://doi.org/https://doi.org/10.1016/j.enpol.2022.113239
[21] MEPC, RESOLUTION. "2013 Guidelines for Calculation of Reference Lines for Use with the Energy Efficiency Design Index (EEDI)." Annex 14 (2013).
[22] International Maritime Organization. "IMO 2020 : Consistent Implementation of MARPOL Annex VI." OMi, 2020.