THE INFLUENCE OF SLOW STEAMING ON FUEL USAGE AND CARBON EMISSIONS OF CONTAINER SHIPS: A CASE STUDY OF THE SURABAYA-MAKASSAR ROUTE

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ABSTRACT

The practice of slow steaming in maritime transport, initially introduced in the 1970s during the first oil crisis, has evolved into a strategy offering both cost reduction and environmental benefits. The overall combined costs for carriers and shippers experienced significant reductions with slow steaming, with extra slow steaming yielding even greater cost savings. While slow steaming is not the sole method to reduce fuel consumption and emissions, it proves to be the most efficient in terms of time and cost. Shipping operators globally recognize its advantages, as it aligns with environmental sustainability efforts by reducing greenhouse gas emissions. This study carried out a comprehensive exploration of the effects of slow steaming on container ships, focusing specifically on the Surabaya-Makassar route. The research aims to learn how much the impact of slow steaming on the ship operation. This study analyzes the impact of slow steaming on container ships in terms of fuel consumption and carbon emissions on the Surabaya-Makassar route. The lowest speed is 5 knots, and the highest speed is 11 knots. At a speed of 5 knots, fuel consumption decreases by 5% compared to the ship's speed at 11 knots. The same applies to the reduction in carbon emissions.

Keyword: Carbon Emission, Container Ship, EEDI, Fuel Cost, Slow Steaming.

Introduction

Greenhouse gas (GHG) emissions in the shipping industry from 2012 to 2018, covering international, domestic, and fishing activities. The total emissions increased from 977 million tonnes in 2012 to 1,076 million tonnes in 2018, with a 9.6% rise. In 2018, CO2 emissions accounted for 1,056 million tonnes, reflecting a 9.3% increase from 2012. Shipping emissions constituted 2.89% of global anthropogenic emissions in 2018, compared to 2.76% in 2012. The study introduces a new voyage-based allocation for international shipping, revealing a 5.6% increase in CO2 emissions from 2012 to 2018, maintaining a stable share of approximately 2% in global CO2 emissions. Additionally, the report notes the first-time distinction between domestic and international shipping emissions based on voyage data, aligning with IPCC guidelines. The carbon intensity of international shipping improved between 2012 and 2018, with an overall average improvement of 21-29% in AER and EEOI metrics, and 22-32% in vessel-based allocation [1]. However, the pace of carbon intensity reduction has slowed since 2015, with annual changes ranging from 1 to 2%. The study also highlights fluctuating carbon intensity performance among individual ships, influenced by various factors such as weather conditions and hull fouling. The emission projections from 2018 to 2050 indicate a potential increase from around 90% of 2008 emissions in 2018 to a range of 90-130% of 2008 emissions by 2050, considering various economic and energy scenarios. These projections are subject to variations based on economic growth rates and the effectiveness of GHG emission reductions from land-based sectors. The report suggests that actual emissions in 2020 and 2021 will be notably lower due to the impact of COVID-19, but the long-term effects on emissions are uncertain and may only result in a marginal decrease over the next decades, potentially within the range of a few percent lower than the projected values. Overall, the report emphasizes that the influence of

COVID-19 on emission projections is expected to be relatively minor compared to the inherent uncertainty in the presented scenarios [2].

The practice of slow steaming in maritime transport, initially introduced in the 1970s during the first oil crisis, has evolved into a strategy offering both cost reduction and environmental benefits. Research indicates that a 10% reduction in vessel speed results in a substantial 27% decrease in engine power and a noteworthy 19% reduction in CO2 emissions for the entire fleet [3]. This reduction extends to emissions of sulfur oxides, nitrogen oxides, and potentially black carbon. The economic benefits of slow steaming, including a projected annual cost reduction of around $63 billion with a 10% speed decrease, are highlighted in studies such as "Smarter Steaming Ahead" [4]. The overall combined costs for carriers and shippers experienced significant reductions with slow steaming, with extra slow steaming yielding even greater cost savings. While slow steaming is not the sole method to reduce fuel consumption and emissions, it proves to be the most efficient in terms of time and cost. Shipping operators globally recognize its advantages, as it aligns with environmental sustainability efforts by reducing greenhouse gas emissions. The analysis of trade routes reveals diverse ship placements, with slow steaming contributing to an 11.1% decrease in CO2 emissions from 2008 to 2010. Additionally, slow steaming enhances schedule reliability by helping ships avoid delays in congested ports [5][6]. It is particularly beneficial for backhaul routes, where ships often carry empty containers, and its flexibility addresses the uncertainty of port turnaround times. Leveraging historical data and simple models can mitigate delays, ultimately enhancing service quality [7][8].

This study carried out comprehensive exploration of the effects of slow steaming on container ships, focusing specifically on the Surabaya-Makassar route. Research aims to learn how much the impact of slow steaming on the ship operation. Analysis of the fuel cost will be conducted, then will be compared to the port dwelling time. Carbon emission produced by the engine will also be considered. From this study, the most efficient operation speed will be suggested to be applied for the ship.

Methodology

Ship Dimensions and Route

A container ship is a type of cargo ship that is specifically designed to carry standardized cargo containers, allowing for efficient loading, unloading, and transportation of goods. These ships have played a crucial role in the globalization of trade by providing a standardized and cost-effective method of moving goods between countries. This research used container vessels with principles dimensions in Table 1.

Table 1. Principle dimension of container

Ship Dimension		
Lpp	74,26	m
Lwl	76,06	m
B	17,4	m
D	5	m
Tf	3	m
Ta	3	m
Δ	2898,56	m^3
	2985,84	tonf
S	1445,23	m^2
[redacted]		
Route	SBY - MKS	
Distance	437	Nmiles

The Tanjung Perak Port, Surabaya, which stretches along the narrow strait between the islands of Java and the island of Madura, requires maintenance and improvements to improve the navigation safety of ships entering and leaving the port. As the second international port in Indonesia, the shipping lane of the Tanjung Perak port can serve ships safely. Apart from that, Tanjung Perak Port should be able to cope with the development of ship visits and the increasing size of ships. Makassar Port is the largest port in Eastern Indonesia. This port has played a role as a trade center since colonial times. Apart from that, this port is located in the sea lanes of the Indonesian archipelago, which is a shipping route that connects the western and eastern regions of Indonesia. This port has a terminal consisting of 2 terminals, namely Soekarno and Hatta bases. Container traffic flow at the Hatta base has increased every year. Where in 1998 the number of containers in operation was only 102,418 TEU's, whereas in 2012 there was an increase to 520,000 TEU's. The increase in the number of containers at the Makassar container terminal from 1998 to 2012 experienced growth ranging from 1.92 – 19.79%. The shipping route from Makassar to

Surabaya and vice versa is an important sea route in commercial shipping in Indonesia.

The container ship route in this research is from Tanjung Perak Port, Surabaya to Soekarno Hatta Port, Makassar, covering a shipping distance of 437 NMiles. Surabaya - Makassar water conditions have wave heights of 1.25 - 2.5 meters based on BMKG data [9].

Fuel Consumption and Cost

The ship's fuel consumption of ships besides to depending on the power of the main engine, it also depends on the type of engine (step and speed), load (load factor) engine, type of fuel used (energy density), the year of manufacture of the engine, the operation length of the ship, the type of fishing gear, and even the level of engine maintenance, and also the habits of the crew in operating the ship. Container ship fuel consumption varies depending on some factors and conditions, e.g. vessel size, age, and condition, engine power, vessel speed and gear configuration, sea state, and weather conditions. The calculation of fuel consumption involves first determining the ship's resistance. The calculation of ship resistance employs Equation 1:

$$RT = \frac{1}{2}\rho.CT.S.V^2 \quad (1)$$

where RT is the total resistance, ρ is fluid density, CT is Coeffisien Resistance, S is a wetted surface area, and V is ship velocity. Once the total resistance on the ship has been calculated, the next step is to determine the engine power required by the ship. The calculation of engine power utilizes the equation:

$$EHP = RT \times Vs \quad (2)$$

$$BHP = SHP/0.85 \quad (3)$$

$$SHP = DHP/0.85 \quad (4)$$

$$DHP = EHP/QPC \quad (5)$$

$$QPC = nh \times nrr \times np \quad (6)$$

Where:

EHP = Effective Horse Power
BHP = Brake Horse Power
SHP = Shaft Horse Power
DHP = Delivery Horse Power
QPC = Propulsive Coefficient

Port Dwelling Time

The dwelling time, or waiting time, sometimes referred to as the time spent loading and unloading containers at the port, is a classic issue that has yet to be effectively addressed in Indonesia. In reality, dwelling time is a seemingly simple problem and constitutes a small part of port management. Key actions to resolve dwelling time include effective port management, streamlining complex bureaucratic processes, and implementing a synchronized system for all services. [10]

The dwelling time represents the vulnerable period required for a container since its unloading from the ship until it exits the port after completing the documentation process. The prolonged dwelling time has significant economic implications, particularly causing consumer goods prices to rise due to the additional costs incurred as a result of dwelling time inefficiencies [11]. Dwelling time is the duration calculated from the moment a container is unloaded and lifted from the ship until it leaves the port terminal through the main gate [12].

The dwelling time spans up to one month, while some instances require a very short period, and others are prolonged due to document waiting times. The licensing process needs improvement since the central point lies in administrative procedures alone. The extended waiting period for loading and unloading, or dwelling time, is caused by various factors, but the most influential factor is the multitude of licensing processes that must be navigated. The government's efforts to address dwelling time issues include improving the flow of goods and implementing information technology systems. Another issue is the abundance of regulatory overlaps, especially those related to cargo storage and the smooth flow of goods.

Cargo shipping in global trade through containerization has become a primary choice. Over 90% of international cargo is transported through ports as transfer interfaces [13]. Ports in India can reduce waiting times for container ships, thereby saving costs. The escalating costs of container terminal development justify the use of computer simulations to aid in planning and policy-making. There has been an exponential increase in cargo and shipping worldwide [14].

Energy Efficiency Index

International Maritime Organization (IMO) has played a crucial role in addressing environmental concerns related to the shipping industry. Energy Efficiency Design Index (EEDI), have been established to enhance energy efficiency and reduce greenhouse gas emissions from ships. The instrument aims to achieve significant GHG emission reductions from ships through enhanced energy efficiency measures [1]. Stakeholders across various sectors contribute to this effort, providing technical insights to refine the EEDI. The EEDI formula is designed specifically for the largest and most energy intensive segments of the global merchant fleet. It covers ship types such as oil and gas tankers, bulk carriers, general cargo ships, refrigerated cargo carriers, and container ships [15].

The EEDI formula, considers various factors, including energy-efficient technologies and alternative energy sources, to determine the overall CO2 emissions. The mechanism provides a flexible and non-prescriptive framework for achieving energy efficiency. The introduction of EEDI for new ships represents a significant step towards reducing CO2 emissions in the shipping industry. The coordinated efforts of the IMO and stakeholders have resulted in a comprehensive framework that addresses existing and new vessels, ensuring a sustainable and environmentally conscious future for international shipping. As the industry evolves, ongoing discussions and refinements to regulations like EEXI and EEDI will be essential to meet the challenges of a rapidly changing maritime landscape [16][17].

In this study, the calculation focusses on the emission produced by the main engine. Carbon emission will be calculated as following approach [18]:

$$\text{Carbon Emission} = \left\{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} C_{FME(i)} SFC_{ME(i)}\right)\right\} \quad (7)$$

Where CFME is the conversion factor fuel oil to CO2 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 equation:

$$PME(i) = 75\% \, (MCR(i) - PPTO) \quad (8)$$

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:

$$EEXI = \frac{CO^2 Emission}{Transport\ work} \quad (9)$$

$$EEXI = \frac{P_{ME(i)} C_{FME(i)} SFC_{ME(i)}}{C\, v} \quad (10)$$

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

Result and Discussion

Ship Resistance

In this study, resistance of the ship was analyzed within the speed range of 5 to 11 knots, considering increments of 0.5 knots. These resistance values obtained through experiments, and exponential regression analysis were carried out as well to broaden the understanding of how resistance changes at different speeds. By expanding the speed variations in the analysis, comprehensive picture of the relationship between speed and resistance were able to be captured. The resistance results gathered will play a crucial role in calculating fuel consumption and assessing the overall energy efficiency of the ship, providing practical insights for optimizing its performance. The resistance value of the ship is concluded in Table 2:

Table 2. Resistance of the ship for each operation speed

VS (Knots)	RS (KN)	BHP (HP)
5	20,019	200,081
5,5	22,753	239,8521
6	25,860	287,5286
6,5	29,391	344,682
7	33,405	413,1961
7,5	37,966	495,3291
8	43,400	590,974
8,5	48,800	710,497
9	55,200	849,941
9,5	63,400	1029,225
10	72,900	1245,030
10,5	81,900	1470,796
11	92,500	1739,722

Fuel Consumption and EEDI

Analysis carried out for the ship fuel consumption and energy efficiency. Analysis carried out by calculating how much fuel the engine needs to operate its power, which will be estimated to the fuel price. The results of the fuel cost estimation were concluded in Table 3 and Figure 1.

In line with the principles of slow steaming, it is observed that as the sailing speed decreases, there is a corresponding reduction in the associated fuel costs. This phenomenon aligns with the overarching theory of slow steaming, wherein deliberately operating at lower speeds is posited as a method to curtail expenses related to fuel consumption.

Table 3. Fuel Cost for each operation speed

VS (Knots)	WFO (ton)	Price ($)	Comparison
5	3,288	$ 2.197,74	75%
5,5	3,583	$ 2.395,09	72%
6	3,937	$ 2.631,91	70%
6,5	4,357	$ 2.912,37	66%
7	4,850	$ 3.241,89	63%
7,5	5,426	$ 3.627,21	58%
8	6,069	$ 4.057,13	53%
8,5	6,867	$ 4.590,76	47%
9	7,759	$ 5.186,65	40%
9,5	8,901	$ 5.950,14	31%
10	10,229	$ 6.837,87	21%
10,5	11,508	$ 7.693,14	11%
11	12,994	$ 8.686,16	0%

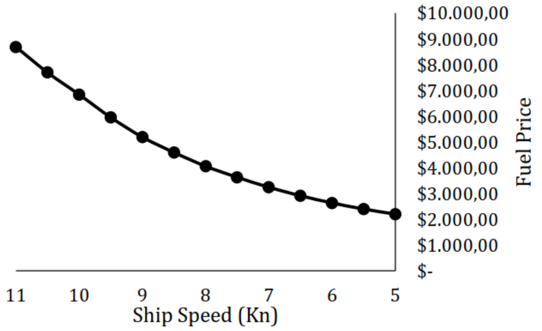

Figure 1. Fuel cost of each operation speed

The slowest speed analyzed, 5 kn, generate the lowest cost for fuel which reach 75% decrease compared to the existing maximum ship speed. The inverse relationship between sailing speed and fuel costs underscores the economic advantages of adopting a more deliberate and energy-efficient approach in maritime operations. The impact of slower ship operation is visible on the result analysis contain in Table 4 and Figure 2.

Table 4. EEDI for each operation speed

VS (Knots)	Carbon Emission (g/H)	EEDI	Comparison
5	120594,427	8,078	75%
5,5	144565,555	8,803	72%
6	173301,539	9,674	70%
6,5	207749,510	10,704	66%
7	249044,868	11,916	63%
7,5	298548,702	13,332	58%
8	356196,794	14,912	53%
8,5	428236,596	16,873	47%
9	512283,030	19,063	40%
9,5	620342,732	21,870	31%
10	750414,595	25,132	21%
10,5	886489,775	28,276	11%
11	1048579,328	31,926	0%

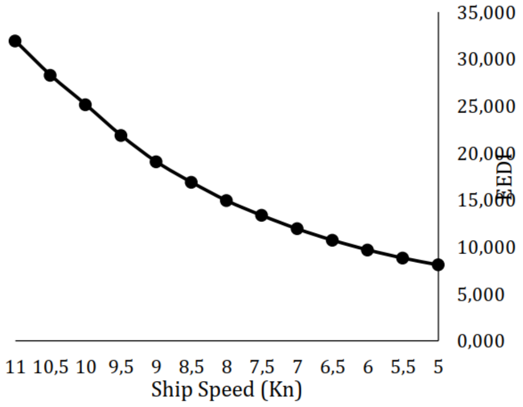

Figure 2. EEDI for each operation speed

Conforming to the slow steaming concept, 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, 5 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.

Comparison on Port Dwelling Time

The results of energy consumption were compared with the dwelling times at each port along the respective routes. This comparison aimed to discern any correlation or influence between energy usage and the time spent at individual ports. As we explore the relationship between energy consumption and port dwelling times, slow steaming's deliberate reduction in sailing speed may influence the overall efficiency of a shipping schedule. While slower speeds contribute to cost savings and decreased carbon emissions, it's imperative to assess how these adjustments may affect the reliability of adhering to planned schedules. The deliberate trade-off between fuel efficiency and timeliness becomes evident, necessitating a nuanced understanding of how slow steaming practices can be strategically implemented to balance economic savings with maintaining dependable shipping schedules. For this study, dwelling time at Makassar port assumed as 141,6 hour, and dwelling time in Tanjung Perak is 67,68 hours [14]. The comparison of each operation speed sailing time to the dwelling time at Makassar port are illustrated in the Figure 3.

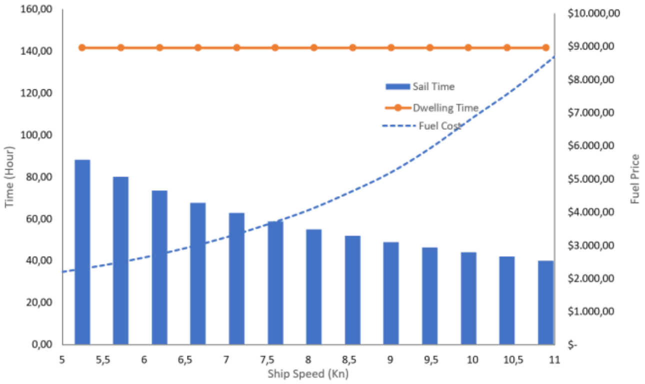

Figure 3. Saling time compared to Dwelling time at Makassar port

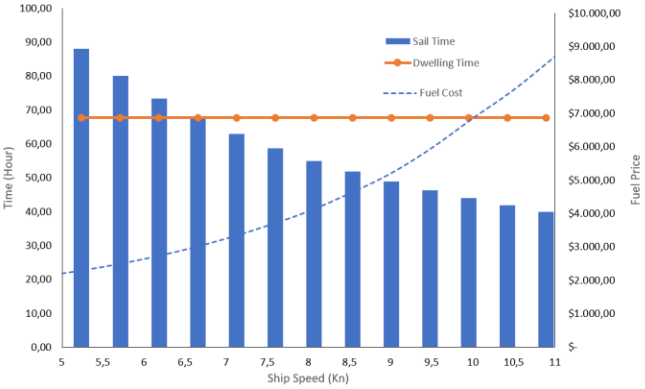

Figure 4. Saling time compared to Dwelling time at Surabaya port

As can be seen from Figure 3, there is a significant difference between the sailing time and the dwelling time at Makassar port. The results show that the hour needed to sail with the slowest operation speed are still far lower than the dwelling time assumed. Therefore, the slowest speed analyzed in this study can be applied in ship operation.

The comparison of each operation speed sailing time to the dwelling time at Surabaya port are illustrated in the Figure 4.

As depicted in Figure 4, the operational speeds capable of reaching the port within the assumed dwelling time range above 6 knots. Any speed below this threshold appears to extend beyond the time limit. This outcome implies that the most efficient speed, balancing low costs while adhering to the port's dwelling time, is approximately 6 knots.

Conclusion

Based on the data that has been explained, it can be concluded that slow steaming has the main benefits of reducing costs, reducing carbon emissions, increasing schedule reliability, and increasing fleet capacity, making it an attractive strategy in maritime transportation. This research analyzes the impact of slow steaming on container ships in terms of fuel consumption and carbon emissions on the Surabaya-Makassar route with the lowest speed is 5 knots, and the highest speed is 11 knots. At a speed of 5 knots, fuel consumption is reduced by 75% compared to a ship speed of 11 knots. The same applies to reducing carbon emissions. Then dweling time at Tanjung Perak Surabaya port is 67.68 hours or 2.8 days. So, the speed required for a container ship is 6 knots so that the ship does not need to moor at the port of Surabaya.

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