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# The Effect of Ship Speeds on Fuel Consumption: A Review

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**Abstract:** The maritime industry has a very strong influence on world trade. In the shipping world, fuel has a very important role to ship operations. The speed of the vessel is an important factor affecting the ship's fuel consumption. In recent years, many research that have been done that focuses on the fuel efficiency of ships. This study is a review of the effect of ship speed on ship fuel consumption. Paper used as literature in this study is a collection of papers from 2000-2017 that discusses the relationship between speed with fuel consumption. There are several methods that using the ship speed as the main parameter to decrease the fuel consumption of the ship.

**Key words:** Fuel consumption, ship emission, ship speed, speed optimization, relationship, efficiency

## INTRODUCTION

The maritime industry has a very strong influence on world trade. Almost 90% of world trade activities use the services of the shipping world. Trading using shipping services is considered more advantageous, due to competitive delivery costs and large capacity. There are now more than 50,000 vessels involved in international trade.

In the shipping world, the total operational cost of a vessel consists of the cost of the vessel (crew expenses, maintenance costs, charter cost) and fuel costs (Meng *et al*., 2015). Fuel costs are the most significant component in total operating costs at a shipping company (Wang, 2016). Fuel has a huge impact. In addition to giving economic influence, fuel also gives the environment influence. Ronen (2011) in his research states that fuel costs account for three quarters of the total cost of ship operations. This case is for the large container ships (Ronen, 2011). Table 1 shows the percentage of total operating cost on a vessel (Valentino *et al*., 2012). It can be seen that fuel consumption has the highest percentage among other types of operating costs.

A decrease in fuel costs can provide substantial savings of the total cost of the vessel. Many ways are taken by shipping companies to reduce fuel consumption. One of which is sailing at lower speed. Due to the non-linear relationship between speed and fuel consumption, it is clear that running at lower speed will consume far less fuel than running at faster speed (Psaraftis and Kontovas, 2014). Another alternative is the alternative of fuel technology that its availability and use will become more common in the coming decades (Ismail and Nugroho, 2010; Semin, 2015; Semin and Bakar, 2013).

Table 1: Total operating cost on a vessel

| Cost type | Cost (%) |
|---|---|
| Ship's crew | 32 |
| Fees and lubricants | 11 |
| Repair and maintenance | 16 |
| Insurance | 30 |
| Administration | 12 |
| Fuel | 47 |
| D.O | 7 |
| Port | 46 |

In recent years, many research that focuses on the fuel efficiency of ships. Semin *et al*. (2008) stated that rising fuel prices and research interest in logistics brings new perspectives on the effect of ship speed on fuel consumption (Abu Bakar and Ismail, 2008). Bialystocki and Konovessis (2016) have done a research about of the estimated fuel consumption of ships and speed curves Bialystocki and Konovessis (2016) and Hulskotte *et al*. (2010) on fuel consumption and exhaust emissions at berthing condition on ports based on on-board surveys (Hulskotte *et al*., 2010; Trodden *et al*., 2015) on fuel use data for efficient shipping operations (Trodden *et al*., 2015; Meng *et al*., 2016) on ship log book data based on fuel consumption modeling with container vessel case studies (Meng *et al*., 2016; Lee *et al*., 2015) on the effect of slow steaming on shipping availability and fuel consumption of vessels (Lee *et al*., 2015; Yao *et al*., 2012) on a study of the use of fuel for ship delivery services.

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Wang *et al.* (2013) mentioned that the amount of fuel consumption depends on ship design and structure but on the other hand also depends on the speed of the ship. This study is a review of the effect of ship speed on ship fuel consumption.

## MATERIALS AND METHODS

This study is a review of several papers on everything about the speed relationship with the fuel consumption. For that reason, the literature used in this paper review focuses on the speed function of the vessel on fuel consumption for some types of vessels. Paper used as literature in this study is a collection of papers from 2000-2017 that discusses the relationship speed with fuel consumption. In this study, some methods are presented from the previous study.

## RESULTS AND DISCUSSION

Fuel consumption is largely influenced by the speed of sailing vessels. As discussed in the previous chapter on the relationship between speed and fuel consumption of ships when speed is increased, the fuel consumption will increase linearly. Some of previous study assumes that daily fuel consumption is directly proportional to the ship speed or fuel consumption per unit distance proportional to the square of the ship speed (Wang, 2016). Equation 1 is the basic formula for finding fuel consumption.

$$FC = BHP \times SFOC \times t \quad (1)$$

Where:

FC = Fuel Consumption (g)
BHP = The power of main engine (kW)
SFOC = Specific Fuel Oil Consumption (g/kWh)
t = Time (h)

The speed of the vessel has an effect on the amount of power released by the main engine.

Figure 1 showing a wide range of technologies to reduce the amount of $CO_2$ and fuel consumption of ships such as improving ship propulsion systems, weather routing, propeller polishing, hull cleaning, speed reductions and more. From the figure it can be seen that emissions reductions and fuel consumption using the speed reduction method has the highest percentage on each type of vessel (except passenger type vessels) compared to other technologies (ICCT., 2011).

Study on the effect of ship speed on marine fuel consumption of vessels related to the maritime field has been done a lot before. According to Psaraftis and Kontovas (2013), speed is an important variable in the world of maritime transport. In general, vessels that sail at high speed have a positive impact and negative impact. The first positive impact is the amount of cargo that can be delivered in more than 1 year. Second, the inventory cost associated with the delivery becomes lower. While the negative impact of sailing at high speed is the increasing of fuel consumption (Wang *et al.*, 2013).

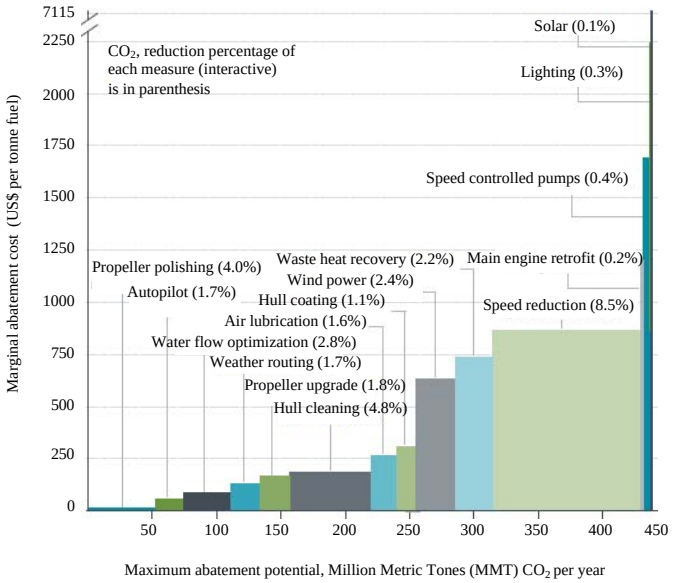


Fig. 1: Technology of $CO_2$ reduction potential and reduction of fuel costs (ICCT., 2011)

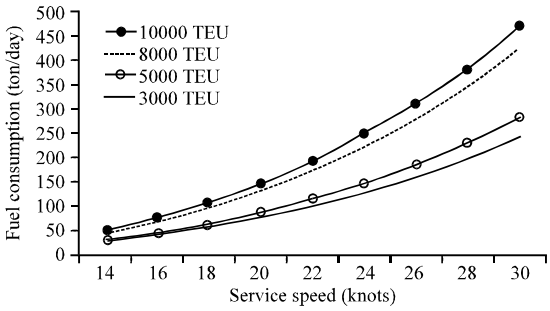


Fig. 2: Graph of sensitivity of fuel consumption and ship speed (Notteboom and Vernimmen, 2009)

Figure 2 shows the sensitivity graph between fuel consumption and ship speed (Notteboom and Vernimmen, 2009). There are graphs for four ships with a capacity of 3000, 5000, 8000 and 10000 TEU. It is clear that if the speed of the vessel is increased by a few knots then the fuel consumption will increase sharply.

Each ship features a speed of design or serviceability that can determine the duration of a ship's voyage. Design speed/service speed is a special vessel speed designed on the ship operating conditions. Design speed is often called normal speed. Design speed depends on the relationship between ship design/resistance and propulsion.

Gusti and Semin (2017) have conducted a study on the effect of speed changes on the level of fuel consumption using data from shipping logbook. The speed is varied, after that of all variations of the speed model is chosen the speed that is considered the most optimal and does not give a significant effect on the performance of the main engine. The method used is using mathematical formula. The results show that the ship can run below the design speed without giving effect to the performance of the engine and can reduce fuel consumption (Gusti and Semin, 2016).

Du *et al.* (2015) recognizes that the combination of ship speed and weather impact on fuel consumption has not been too much of a focus on previous studies. According to that study, the uncertainty in the level of fuel consumption on a vessel caused by weather conditions is not shown in previous research. Robust optimization models and suitable algorithm solutions are presented as to produce different fuel budget values ??that reflect different levels of conservatism from fuel efficiency experts in container shipping companies. The optimization model can be transformed into MILP (mixed integer linear programming) form. They used the Bertsimas and Sim (2003) algorithms on common combinatorial problems and polynomial time algorithm designs based on solutions of some problems of path-shooting (Du *et al.*, 2015).

Bialystocki and Konovesis (2016) have done a study about the fuel consumption and speed estimation curves. The paper takes an operational approach to obtain an accurate fuel consumption curve and speed. The main fundamental factors that can affect the curve are ship laden and displacement, weather force and direction, hull and propeller roughness. Based on these data, obtained a series of simple and feasible algorithms that can predict fuel consumption based on ship speed function. This is important because fuel savings are taken on the right decisions, which are cost-efficiency and environmentally friendly priorities (Bialystocki and Konovessis, 2016).

Smith *et al.* also conducted a review paper on different perspectives on ship speed on the subject areas of energy efficiency, engineering, economics and the environmental impact of ships. According to him, the speed of ships in the world of shipping plays an important role for both customers and owners or ship operators. For customer/passenger, the speed of the ship determines the duration of the delivery of goods/duration of passenger travel from one place to another. For the case of a freight ship, it determines whether the quality of the goods shipped will remain the same and when the goods will arrive in the market. Speed also affects ship owners and operators because small changes of speed can have a significant effect on the energy efficiency of ships that ultimately affect the operational cost of the vessel. In the paper, we present the initial models and results of the paper used as literature and the pace relation to IMO policies and regulations.

Some ports have operating time regulations in 1 day, such as not operating at night or on weekends. In addition to time restrictions on operation, at some ports there are also draft limitations on ships due to water conditions. Only ships of a certain size can enter the port. Those rules that cause multiple time windows apply to the port (Kim *et al.*, 2016). From this background, Kim *et al.* (2016) have conducted a study on ship speed optimization to reduce the fuel consumption of ships using multiple time windows. Optimization using Non-linear Mix Integer Programming (NMIP) by developing mathematical models and algorithms. The computational experiments show that the proposed algorithm is very efficient to find the optimum speed (Kim *et al.*, 2016).

Banawan *et al.* (2013) have done a research on reducing fuel consumption and emissions by decreasing speed on catamarans. Decreasing the speed is expected to reduce fuel consumption and $CO_2$ emissions from ships.

This study analyzes the methods used to determine the variations in fuel consumption that may occur and their impact on ship emissions when implementing a catamaran speed reduction strategy. The comparative methods are power-speed law, experimentation and software usage (Maxsurf). The results show that there is a significant convergence point between the published theoretical model and those obtained from the real data (Banawan *et al*., 2013).

Guichen and Zhifei (2014) have conducted a research on ship speed reduction strategies and high viscosity fuel utilization on ship engines. Reduce the speed of main engines and utilize high viscosity fuel by shipping companies to reduce shipping costs, improve economic operations and increase shipping profits. Method of calculation in this research using mathematical formula. The results with the decrease of the main engine rotation at the speed of ship service indicate that it can decrease fuel consumption significantly (Guichen and Zhifei, 2014).

Gorski *et al*. (2013) have done a research on the effect of the ship's main operational parameters on fuel consumption. These parameters include boat speed, laden boats and trim. The method that used in this research is using some mathematical formulas and computational simulations. Presented several sample problems on each parameter. From the analysis of the examples presented, it shows that the effect of ship operational parameters on the level of fuel consumption cannot be explained by simple relationships. It was found that the effects of trim changes depend on the speed of the ship and the average draft. The most important factor with this is the shape of the stomach. Required computational model to determine the conditions that result in reduction in fuel consumption of ships (Gorski *et al*., 2013).

Wang and Meng (2012) have conducted research on sailing speed optimization on container ships. The optimization method used in this research is Mixed Integer Nonlinear Programming (MINP). The proposed model and algorithm can be applied to real case studies for global shipping companies. The contribution of this research is twofold. First, calibrate the relationship of fuel consumption to speed of vessel using historical operating data. The regression analysis shows that fuel consumption also depends on voyage legs which contradicts the assumptions of many previous studies. Second, it proposes a speed velocity optimization problem for container ships in liner shipping networks (Wang and Meng, 2012).

Gusti and Semin (2016) have conducted a research on the effect of speed on fuel consumption and exhaust emissions of a vessel. The calculation is performed using a simple mathematical formula. Speed is varied to see the effect on fuel consumption and ship emissions. The results showed that the higher the speed, the level of fuel consumption and ship emissions also increased (Gusti and Semin, 2016).

## CONCLUSION

In the shipping world, fuel has a huge impact. In addition to giving economic influence, fuel also gives the environment influence. Given the cost of fuel is the largest cost of total vessel operating costs. Because of this, fuel consumption savings are important. Because of the non-linear relationship between fuel consumption and speed, speed optimization is one of the ways in which shipping companies or shipowners can save fuel. This study is a review of the relationship speed and fuel consumption on the ship. This study is a collection of research on the effect of speed on the level of fuel consumption of ships. There are several methods that using the ship speed as the main parameter to decrease the fuel consumption of the ship.

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