

## Slow Steaming in Container Shipping

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### Abstract

*International supply chains heavily rely on maritime shipping. Since the beginning of the latest economical crisis, the containership fleet is slowing down. This paper gives a short overview of the slow steaming history as well as the widely assumed coherence between a ship's speed and its fuel consumption. Calculating fuel consumption as a function of speed provides decision support regarding the decision to which extent slowing down should be performed. It can be assumed that, compared to sailing at full speed, a speed reduction has a positive economic and also environmental impact. This paper is focused on the economic aspects. We show the considerable cost saving potential of a lower ship speed as a result of the decreasing fuel consumption. In combination with other variables of a container vessels' profit function, this may lead to the profit optimizing speed of a container carrier.*

### 1. Introduction

In the last decades, container shipping companies were trying to deliver their goods as quickly and reliably as possible. Even the ever-increasing fuel prices could not stop this trend. The resulting costs could be compensated by the growing revenues resulting from the worldwide increasing demand of transport capacity due to globalization. However, based on the impacts of the economic crisis on the global trade market in the last years, activities on the transport market as well as revenues dropped severely. Not only the demand of transport capacity was shrinking in an unexpected way, but additionally the supply was growing extremely fast. This vicious cycle seems typical for the container shipping industry. In an economic boom, shipping companies order large capacities (a large number of ships and/or ships with a large capacity), which are delivered later, possibly in a

recession phase. In combination with the trend of growing ship size and the decreasing demand as a result of a recession, this cycle leads to a large mismatch between supply and demand of transport capacity. As a result, freight rates decrease. One strategy to cut down operational costs is to moor some vessels with minimal crew for a longer time until new cargo has to be loaded. Indeed, an increase of the number of laid-up vessels could be observed as a result of the global crisis.

An additional strategy for shipping companies is to slow down vessels compared to sailing at full speed. The basic idea of this slow steaming is not new as it is well known, that the fuel consumption of large cargo vessels is rising exponentially with a vessel's velocity. Due to this fact, ships were operated with a lower speed in former times as well. But compared to today, it was never applied to such a large part of the worldwide fleet because of the exceptional circumstances in the latest crisis. However, even nowadays, as the crisis in the transport sector is nearly over, slow steaming remains a common operating mode for container ships. Due to the lack of interest in former times, important parts of the theoretical background of slow steaming are unknown or not reflected in some parts of the literature.

In this paper we provide decision support regarding the question to which extent slow steaming is profitable and how profit optimizing vessel speeds can be calculated. After a literature review we discuss various effects of slow steaming in Section 3. Calculations are shown in Section 4 and Section 5 concludes the paper.

### 2. Literature review

The calculation of optimal speed for freight vessels and related performance indicators such as freight rates were analyzed a few decades ago, e.g., in [9, 10]. In [27], an analysis of the effect of oil price on the optimal vessel speed is presented. The calculations for

optimal speed are different in these publications but the main principles of the relationship among impact factors and speed seem to be correct. However, the research was based upon the common but old-fashioned ‘admiralty formula’ which assumes that the daily fuel consumption is rising by the power of three with regard to the speed. This admiralty formula stems from times when ships were operated by coal. In particular today, this formula is not appropriate as a basis for reliable calculations of fuel consumption under real world conditions.

While the speed of a vessel may be optimized, especially in the liner and container shipping business various side constraints may come into play. Among others, this concerns the interplay between different vessels of a fleet operating to achieve some common goals. In [24], fuel costs are modeled as a nonlinear function of a vessel’s speed. The problem of vessels’ allocation to routes is combined with the problem of speed selection in an optimization model. Based upon [15, 25], an integer programming model for minimizing operating and lay-up costs for a fleet of liner ships operating on various routes is presented in [26]. Basic fuel consumption characteristics of vessels are used as model input. However, environmental aspects were not in the focus at that time. In [17], the optimal vessel speed considering costs and environmental aspects by lowered fuel consumption is briefly analyzed and discussed.

Independent from the container shipping industry, [3] provides a simple and yet effective spreadsheet based approach for saving considerable amounts of fuel for US navy ships without the need of new equipment or ship modifications based upon analysis of fuel curves that show the fuel consumption as a function of power plant mode and speed, based upon ship engineering publications. It is assumed that the ship can operate with one or more of its propulsion plants idled to save fuel. According to [2], this estimation of fuel consumption is one part of the logistics planning factor ‘demand,’ which is used for optimizing the US navy’s supply by planning the worldwide fleet of transport ships.

In [23], the effect of high fuel prices on the service (e.g., the schedule, speed of vessels, number of vessels serving a loop) of container companies providing liner services on the Europe-Far East trade is analyzed. In [6] a profit function is developed reflecting container-ship and route characteristics. Two scenarios are considered (no extra ships and extra ships for maintaining a given cargo flow) as well as the interrelation of costs, fuel prices, speed, fuel use, and carbon dioxide (CO<sub>2</sub>) emissions. However, one basic assumption is that the per-trip fuel consumption of the main engine is basically given by the cubic law with

respect to the ratio of operational and design speed. According to [7], the relationship between speed and fuel consumption depends on an engine’s type and its load. In particular with loads below 25% maximum continuous rating, common rules of thumb fail. The study reports potential emission reductions in the order of 30% without the need of specific slow steaming equipment. Recent calculations and detailed analysis of economical and technical aspects in [11, 12] indicate that the fuel savings potential by speed reduction is considerably higher than claimed in numerous previous publications.

According to our observation as well as [22] in most formulations of maritime transportation problems, time and cost of sailing are not varied regarding speed. The latter paper builds upon [8] and provides an extended formulation by introducing variables for the sailing speed for each ship and sailing leg, as well as an adjusted cost function and constraints to incorporate speed as decision variables. For advising solution methods such as multi-start local search based methods the authors advise discretized arrival times. In [4], it is shown for container shipping that slow steaming has reduced emissions by around 11% over the years 2008-2010 without the adoption of new technology. Furthermore, a bunker break-even price with the slow steaming strategy and the resulting emission reduction being sustainable in the long run is calculated. For the main container trades it is found that considerable reductions can only be sustained with a high bunker price of at least \$350–\$400. Therefore, ‘market-based solutions’ (e.g., tax levies and/or cap-and-trade systems) are recommended in order to sustain bunker prices.

Operational decisions aiming at fuel and emission savings, such as slow steaming, in combination with strategic decisions (e.g., fleet, alliances) are useful for vessels that are already built and in operation. However, there are ways of influencing a vessel’s economic performance during the early designing and construction (or modification) phase of a ship by making decisions on, e.g., a ship’s shape, engine, propulsion, fuel, etc. (see, e.g., [14, 29, 32]).

### 3. Effects of slow steaming

In practice as well as many publications simplified formulas are used to describe the costs in relation to velocity of vessels. To better understand related approximations and to be able to better judge on specific calculations we provide some physical background. This might seem superfluous at first sight. That is, one might argue that decision support is possible without this due to available systems and prototypes (see, e.g., the contributions in [2, 3] as well

as [21]). However, based on current practices and references especially in the container shipping industry including maritime economics one needs to convince that previous approaches are somewhat too simplified to be used as entry points for building decision support systems. Moreover, it seems necessary to consider the option to provide entry points into necessary extensions in problem settings. One among several examples refers to situations, when optimal speed or changes in speed influence the number of employed vessels necessary to keep frequencies of sail.

### 3.1. Positive effects

For companies in the shipping sector, the main reason to implement slow steaming was to reduce the consumption of petroleum products in the combustion of the main engine. These products are fuel, but also lubricating oil, which is combusted in large two-stroke engines. This paper starts by analyzing the effects on the fuel consumption, where a large rise in price was noticeable. Compared to the nineties of the last century, the average price of heavy fuel oil increased until the period of 2007/2008 by more than 800% [5]. Thus, there was a high pressure to cut down costs in this sector.

Claims in articles or publications regarding the potential of fuel saving by slow steaming are often not replicable as they do not explain required details of the ascertainments. But as shown below, the physical principles of the fuel consumption are too complex, results are ambiguous, and conclusions are disputable, making simple and generalized explanations virtually impossible.

The physical formula for the force  $F_R$  needed to move a ship through a flow depends on the velocity difference between the ship and the surrounding medium and consists of three single forces [31]:

- the wave resistance  $R_W$ , which is a result of the energy needed for the wave field around the ship's hull,
- the turbulent flow resistance  $R_T$ , resulting from occurring vortexes due to collapsing flow around the hull,
- the laminar flow resistance  $R_L$ , which is the frictional resistance between a ship's hull and the medium.

In combination with the related velocity dependencies, the needed force can be described by the following function (1), with parameters  $a_W$ ,  $a_T$ , and  $a_L$  reflecting the wave resistance, the turbulent flow resistance, and the laminar flow resistance:

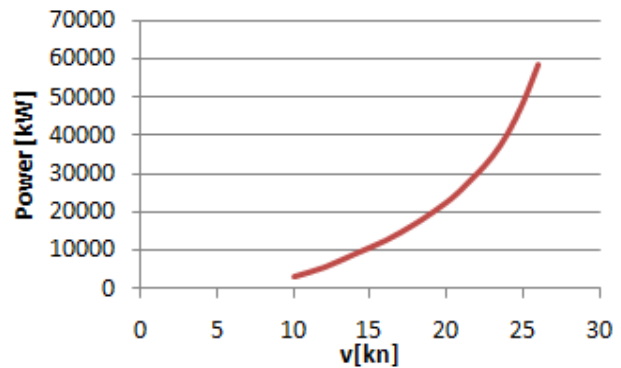
$$F_R = R_W + R_T + R_L = [a_W + a_T] \cdot v^3 + a_L \cdot v \quad (1)$$

To travel a distance  $D$  with a constant ship velocity  $v = D/t$  against this force, the work  $W_R = F_R \cdot D$  is required. In the time  $t$ , the power  $P_R = W_R/t = F_R \cdot v$  must be reached. Inserting into formula (1) leads to a ship's power requirement depending on the velocity:

$$P_R = [a_W + a_T] \cdot v^3 + a_L \cdot v^2 \quad (2)$$

The power requirements of a 8,500 TEU container vessel as a function of the velocity is depicted in Fig. 1. This function is valid for the parts below and above the waterline. But the coefficients  $a_W$ ,  $a_T$  and  $a_L$  do not only depend on the flowing medium and the relative velocity between ship and medium, but they also depend on many other factors such as the scale of the hull, fouling, or the varnish condition. Furthermore, these conditions can change over time and in dependence of the speed as well, e.g., fouling decreases with increasing speed. So the theoretical dependence of the required power on the ship's speed can hardly be represented more precisely. Even more factors have to be considered to calculate the fuel consumption. In particular the levels of efficiency of the engine, driveshaft and propeller have a considerable impact. The speed dependence of these levels of efficiency exacerbates the calculation, too. Therefore, it is an option to determine the coherence of the fuel consumption empirically. According to the approach in [11], the fuel consumption  $FC_{nm}$  per nautical mile (nm) can approximately be represented by:

$$FC_{nm} = FC_{min} + c_F \cdot v^n \quad (3)$$

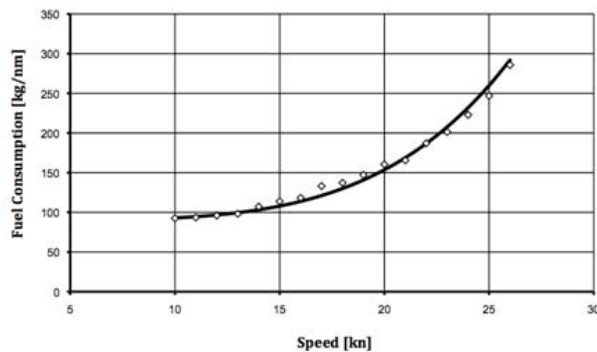


**Figure 1. Power requirements (8,500 TEU container vessel) as a function of the velocity; Data source: [13]**

With  $c_F$  as fuel consumption parameter and based upon the engines minimum consumption  $FC_{min}$  to drive at all, this approach is assuming a fuel consumption exponentially rising with the speed. There are different statements in scientific papers about the speed dependence. The most common assumption

about this is the admiralty formula. But because of the shown complexity, a ship's fuel consumption must be appraised individually instead of applying generalized simplified values, e.g., based upon the admiralty rule, which may result in misleading calculations. Considering, e.g., [3], it seems necessary to use detailed fuel burn rate tables for different ship types based upon empirical observations in the container shipping industry. The following calculations are based on the consumption of an 8,000 TEU container vessel [16] for showing a real-world example of a ship's fuel consumption (see Fig. 2).

Based on a least squares approximation and formula (3), the following function values are obtained:  $FC_{min} = 90$ ,  $c_F = 0.00012$ , and  $n = 4.4$ . The fuel consumption per mile of the regarded ship rises in dependence of the speed to the power of 4.4. Additionally, it must be pointed out, that the consumption per mile is one power less than the daily consumption. According to [11], this is a characteristic value for large cargo ships. This shows that for container ships the potential for fuel savings is considerably higher than assumed and claimed in numerous previous publications.



**Figure 2. Fuel consumption as a function of vessel speed (8,000 TEU container vessel); Data source: [16]**

For example, with data provided in Table 1, a container vessel on a trip from Europe to Far East is expected to save approximately 2,550 tons of fuel, resulting in financial savings of 1,785,000 \$.

**Table 1: Data used for exemplary calculation of fuel savings by slow steaming**

Parameter	Value	Unit
Distance	24,000	nm
Fuel Price	700	\$/t
Speed	$v_1 = 25$	kn
	$v_2 = 20$ (slow steaming)	[nm/h]

Data sources: [5, 16, 33]

As mentioned above, parts of the lubricating oil are combusted inside the engines as well. These consumptions are also a considerable cost factor with price increases similar to the fuel prices. The lubricating oil consumption depends on the speed dependent power  $P_E$  generated by the engine and its performed work  $W_E(v) = P_E(v) \cdot t$ , respectively. As in formula (3), a certain minimal consumption  $LC_{min}$  is assumed, resulting in lubricating oil consumption per nautical mile as shown in formula (4) with  $c_L$  as lubricating oil consumption parameter:

$$LC_{nm} = LC_{min} + c_L \cdot W_E^m \quad (4)$$

By assuming a linear coherence between fuel consumption and lubricating oil consumption, it is possible to assess the dimension of the cost saving potential of formula (4) even without a specific power demand curve. Based on the values in Table 2, the cost savings for the above shown example trip from Europe to Far East are 63,000 \$ for lubricating oil.

**Table 2: Data used for exemplary calculation of lubricating oil savings by slow steaming**

Parameter	Value	Unit
Specific fuel oil consumption	175	g/kWh
Specific lubricating oil consumption	0,8	g/kWh
Lubricating oil price	4,950	\$/t
Speed	$v_1 = 25$	kn
	$v_2 = 20$ (slow steaming)	[nm/h]

Another positive effect resulting from a decreased fuel consumption is the reduction of some emissions. While nitric oxides and soot emissions may rise under certain circumstances, the amount of CO<sub>2</sub> and sulfur oxide (SO<sub>x</sub>) is decreasing severely, which is in particular a benefit because there is some pressure on the ship owners to reduce these emissions. Since the International Maritime Organization (IMO) is exacerbating its regulations on the SO<sub>x</sub> emission it has also announced regulations on CO<sub>2</sub> emissions for the near future (see, e.g., [30]).

### 3.2. Negative effects

Obviously, a ship can move less cargo in a fixed time, when it is operated with a lower speed. This coherence is represented in the maximum transport performance  $F_s$ , with  $cap_{eff}$  as the actual usable cargo space (effective capacity) which is less than the nominal cargo space due to weight limitations [28],

and  $f_T$  as the maximum number of round trips during the operating time period  $T_O$ :

$$F_S = cap_{eff} \cdot f_T = cap_{eff} \cdot T_O / T_T \quad (5)$$

The required time of a tour  $T_T$  is the sum of the times spent at sea (shipping)  $T_S$  and in harbors (waiting)  $T_H$  as shown in formula (6), with  $t_{H,i}$  as time spent in a specific harbor of segment  $i$  within the tour,  $D_i$  as distance of that segment, and  $v_i$  as speed on that trip:

$$T_T = T_H + T_S = \sum t_{H,i} + \sum D_i / v_i \quad (6)$$

Here, the following differentiation is necessary: If the freight performance of a ship is lower than the demand of transport performance  $F_D$ , a lower speed does not result in a loss of revenues. Contrary, slow steaming could reduce the mismatch between supply and demand by absorbing a large amount of the global container ship fleet's capacity. So with  $F_{D,i}$  as demand of transport performance on a specific trip  $i$ , the actual transport performance on that trip is defined as  $F_{P,i} = \min(F_S; F_{D,i})$ . Thus, the freight income  $I_S$  for a tour is the sum of the income per trip, which depends on  $F_{P,i}$  and the trip specific freight rates  $p_{FR,i}$ :

$$I_S = \sum I_{FR,i} = \sum p_{FR,i} \cdot F_{P,i} \\ = \sum p_{FR,i} \cdot \min(F_S; F_{D,i}) \quad (7)$$

Hence, in case of demand exceeding the maximum transport performance, a lower speed results in a proportional loss of income for the shipping company. Another negative factor of the extended traveling time affects shippers and their customers since the longer a trip takes the longer the cargo is bound to the sea. This means additional capital costs for shippers and for their customers (see, e.g., [12] for a simple calculation, or [1] for considering an internal rate of return for calculating opportunity costs). From this point of view, faster operated ships are more attractive to both of them. This has to be regarded as a competitive disadvantage of slow steaming. However, this aspect is not in the focus of the following calculation. A brief discussion of the effectiveness and costs of slow steaming for reducing emissions is, e.g., presented in [6].

#### 4. Calculation of profit optimizing speed

For calculating the profit maximizing vessel speed, a profit function is required (the calculation is based upon [11, 12]). Profit is the difference of revenue and costs. The revenue is the above mentioned freight income. The total operating cost of a vessel  $C_V$  comprises the following three costs:

- consumption costs  $C_C$ , as the sum of discussed fuel consumption costs  $C_F$  and lubricating oil consumption costs  $C_L$ ,
- harbor costs (e.g., fees)  $C_H$ ,
- usage costs  $C_U$ , e.g., labor costs, capital consumption, maintenance, insurance.

Usage costs can be considered as more or less fixed with respect to the vessel's speed. If the vessel is chartered, the value should be adjusted by taking the contract's details into account (e.g., by deducting costs for lubricating oil). For the sake of simplicity, we assume fixed  $C_U$  in the subsequent calculation. Harbor costs do not depend on a vessel's speed. Therefore, one can simplify the calculation by considering average harbor costs. With  $N_H$  being the number of harbors on the round trip and  $p_H$  as the average harbor price,  $C_H$  can be calculated as follows:

$$C_H = f_T \cdot N_H \cdot p_H = \frac{T_O}{\sum t_{H,i} + \sum D_i / v_i} \cdot N_H \cdot p_H \quad (8)$$

Consumption costs for shipping are the largest and most important part of the total operating costs, with fuel costs being the largest part of the consumption costs. Total fuel costs are the sum of costs for each segment of a tour, resulting from the fuel consumption per segment and fuel costs for that segment. Thus, fuel costs  $C_F$  can be calculated as follows:

$$C_F = \sum p_{F,i} \cdot FC_i \cdot D_i \\ = \sum p_{F,i} \cdot (FC_{\min} + c_F \cdot v_i^n) \cdot D_i \quad (9)$$

Costs for lubricating oil can be derived from the above mentioned power requirements. Since this part of shipping costs is by far the less significant part compared to the fuel costs, we simplify the calculation by incorporating them with a specific percentage of the fuel costs. Herewith, we assume a proportional interdependence of power and fuel consumption (i.e., a constant specific fuel oil consumption independent from engine load). This simplification from real world seems appropriate for our purpose, in particular taking modern electronic motor management into account. With a given percentage  $a_{\%}$ , the costs for lubricating oil  $C_L$  can be calculated as in (10), with  $p_{L,i}$  as the trip specific price for lubricating oil:

$$C_L = \sum p_{L,i} \cdot (FC_{\min} + c_F \cdot v_i^n) \cdot D_i \cdot a_{\%} \quad (10)$$

For an operating time period  $T_O$ , the resulting consumption costs  $C_C$  are calculated as :

$$C_C = f_T \cdot (C_F + C_L) \\ = \frac{T_O}{\sum t_{H,i} + \sum D_i / v_i} \cdot (C_F + C_L) \quad (11)$$

The sum of the three cost components results in the total operating costs  $C_V$  of a vessel:

$$\begin{aligned}
C_V &= C_U + C_H + C_C \\
&= C_U + \frac{T_O}{\sum t_{H,i} + \sum D_i/v_i} \cdot N_H \cdot p_H + \frac{T_O}{\sum t_{H,i} + \sum D_i/v_i} \cdot \\
&\quad (\sum p_{F,i} \cdot (FC_{\min} + c_F \cdot v_i^n) \cdot D_i)(1 + a_{\%}) \quad (12)
\end{aligned}$$

This formula allows for deriving the cost optimizing speed. This knowledge about the relationship of speed and costs is an important instrument in fleet planning allowing for even higher profit than in case of operating with profit maximizing speed. However, subsequently the paper is focused on the profit optimizing speed. Hence, the profit is calculated as difference between revenue and costs.

The revenue or income function is given by formula (7). With the maximum transport performance exceeding demand, the profit optimizing speed equals the optimal speed with regard to costs. Therefore, it is now assumed that the vessel's capacity is completely utilized. In this case, the function for the income generated by a utilized vessel is given by formula (13):

$$\begin{aligned}
I_V &= \sum p_{FR,i} \cdot F_S \\
&= \sum p_{FR,i} \cdot cap_{eff} \cdot \frac{T_O}{\sum t_{H,i} + \sum D_i/v_i} \quad (13)
\end{aligned}$$

The profit function  $P_V$  as difference between income and costs is:

$$\begin{aligned}
P_V &= I_V - C_V = I_V - C_U - C_H - C_C \\
&= \sum p_{FR,i} \cdot cap_{eff} \cdot \frac{T_O}{\sum t_{H,i} + \sum D_i/v_i} \\
&\quad - C_U - \frac{T_O}{\sum t_{H,i} + \sum D_i/v_i} \cdot N_H \cdot p_H - \frac{T_O}{\sum t_{H,i} + \sum D_i/v_i} \cdot \\
&\quad (\sum p_{F,i} \cdot (FC_{\min} + c_F \cdot v_i^n) \cdot D_i)(1 + a_{\%}) \quad (14)
\end{aligned}$$

This function allows for calculating the profit optimizing speed for each segment of a tour. This approach is simplified by making some assumptions close to reality in order to calculate values without requiring computer based approximation. First of all, consumption functions can be simplified by assuming that  $v_i$ , the speed for a segment  $i$ , can be expressed as deviation from an average speed  $\bar{v}$  resulting in  $v_i = \bar{v} \pm \Delta v_i$ . Since the fuel consumption increases disproportionately high to the increase in speed, the positive deviations are always higher than the negative ones. Thus, the fuel consumption is always higher with various speeds in various segments compared to shipping with constant speed throughout the entire trip having the same total travel time. Furthermore, the required multiple acceleration for shipping with different speeds on a segment results in additional fuel consumption. This leads to the basic rule that a minimum of fuel consumption can be achieved by shipping with a constant speed on each segment. Secondly, it is assumed that the shipping time clearly exceeds the wait time at harbors ( $D/v \gg N_H \cdot t_H$

$\rightarrow 1/(N_H \cdot t_H + D/v) \sim v/D$ ), which is in addition taken as an average value for further simplification. Lastly, constant freight rates ( $p_{FR} = \sum p_{FR,i}/N_H$ ) and constant prices for fuel and lubricating oil are assumed. The simplifications and resulting changes of the profit function are listed in Table 3.

**Table 3: Simplifications for profit calculation**

Simplification	Calculation without simplification	Calculation with simplification
Constant speed	$\sum D_i/v_i$	$D/v$
Shipping time $\gg$ wait time at harbors (average)	$D/v + N_H \cdot t_H$	$D/v$
Constant freight rate	$p_{FR,i}$	$p_{FR}$
Constant prices for fuel and lubricating oil	$p_{F,i}$ $p_{L,i}$	$p_F$ $p_L$

By considering these assumptions, formula (14) for calculating the profit can be simplified to:

$$\begin{aligned}
P_V &= T_O \cdot \left( \frac{p_{FR} \cdot cap_{eff}}{D} \cdot v - C_U - \frac{N_H \cdot p_H}{D} \cdot v - \right. \\
&\quad \left. (p_L \cdot a_{\%} + p_F) \cdot (FC_{\min} + c_F \cdot v^n) \cdot v \right) \quad (15)
\end{aligned}$$

For calculating the profit optimizing speed  $v_{opt}^P$ , the derivative of function (15) with respect to  $v$  is set to zero resulting in:

$$\begin{aligned}
\frac{dP_V}{dv} &= T_O \cdot \left( \frac{p_{FR} \cdot cap_{eff}}{D} - \frac{N_H \cdot p_H}{D} - (p_L \cdot a_{\%} + p_F) \cdot \right. \\
&\quad \left. (FC_{\min} + c_F \cdot v^n) \right) = 0 \quad (16)
\end{aligned}$$

Solving (16) for  $v$  results in the profit optimizing speed  $v_{opt}^P$  as follows:

$$v_{opt}^P = \left( \frac{p_{FR} \cdot cap_{eff} - N_H \cdot p_H}{(p_L \cdot a_{\%} + p_F) \cdot D \cdot (n+1) \cdot c_F} \right)^{\frac{1}{n}} \quad (17)$$

With given data, this formula allows for calculating  $v_{opt}^P$  for a trip of any vessel. This is exemplified by a calculation for a round trip from Europe to Far East.

Table 4 shows data required for the calculation of (17), resulting in  $v_{opt}^P = 20.09$  kn. Taking this profit-optimal speed  $v_{opt}^P = 20.09$  kn and formula (15) for profit calculation into account, the maximal profit for this example can be calculated with  $P_{V,opt} = 25.1$  million \$, while shipping with design speed instead of profit-optimal speed results in a profit of 17.4 million \$ only. The optimized speed results in a profit increase of 7.7 million \$ or 44% compared to the design (maximum) speed.

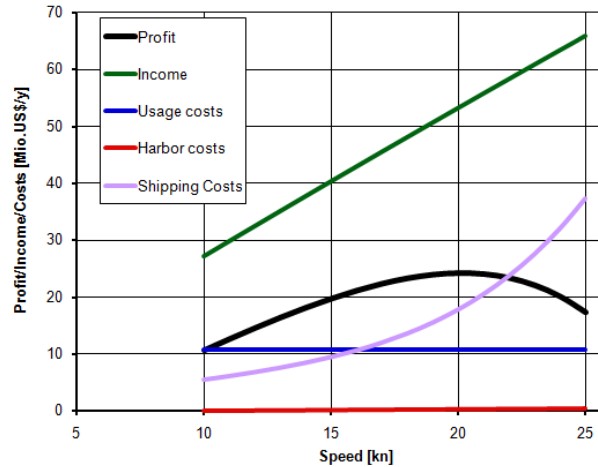
**Table 4: Data for calculating profit optimizing speed for an exemplary trip Europe – Far East**

Influencing factor	Symbol	Value
Effective capacity (with $\rho = 0.87$ ; [28])	$cap_{eff}$	8,000 TEU · 0.87 $\approx 7,000$ TEU
Trip length	$D$	2 · 24,000 nm = 48,000 nm
Operation time	$T_O$	1y → 360d → 8,640h (5 days for maintenance)
Number of harbors	$N_H$	2
Speed exponent	$n$	4.4
Consumption parameter fuel 1	$c_F$	0.00012
Consumption parameter fuel 2	$FC_{min}$	90
Lubricating oil consumption [%]	$a_{\%}$	0.005
Fuel price	$p_F$	700 \$/t = 0.7 \$/kg
Lubricating oil price	$p_L$	4,950 \$/t = 4.95 \$/kg
Harbor price	$p_H$	42,000 \$
Freight rate	$p_{FR}$	2 · 1,100 \$/TEU = 2,200 \$/TEU *
Usage costs (without lubricating oil)	$C_U$	30,000 \$/d = 1,250 \$/h

\* Note: The freight rate is assumed to be equal for both directions for the sake of simplicity [36]; see, e.g., [12] for a calculation with different rates

Revenue, costs, and profit as functions of the speed are depicted in Fig. 3, demonstrating that the cost-optimizing speed is only affected by the relation of shipping costs and freight rates. However, this quantitative, cost-oriented horizon should be broadened by taking also qualitative factors such as image improvement (environmental friendly shipping) or customer satisfaction into account. These factors should be observed during real world operation in order to be able to react as quickly as possible.

Furthermore, it can be seen that the profit optimizing speed is usually higher than the cost optimizing speed. The profit optimizing speed decreases inversely proportionally with the 3<sup>rd</sup> root of fuel price slightly faster than the cost optimizing speed. Contrary to the cost optimizing speed, the profit optimizing speed is independent from usage costs. In addition, with increasing number of harbor stops or harbor time, the profit optimizing speed is only moderately decreasing. As far as the freight rates increase proportionally to the travel distance, the profit optimizing speed does not change significantly.



**Figure 3: Income, Costs, and Profit as functions of vessel speed**

## 5. Conclusion

The main purpose of this paper was to provide an overview over the main financial effects of slow steaming in order to evaluate economic aspects of this operating mode of vessels which is receiving considerable interest in particular as a result of the last economic crisis.

Looking at these issues can be done from various sides. In different disciplines and for different purposes the objective may be different, i.e., a shipping liner may look at ‘slow steaming’ from a different perspective than an operator in case where ships may be looked at as single entities.

The most important positive impact for a shipping company is the savings of fuel and, therefore, fuel costs. However, analysis of literature and communication with experts revealed that some literature is based upon false assumptions regarding physical aspects and volume of cost savings. Taking main drivers of fuel consumption into account, it can be concluded that the often applied cubic function, based on the old admiralty formula, is not appropriate for reflecting the increase of fuel consumption as a result of increased speed. The gained insight was used for calculating fuel consumption in an exemplary case in order to demonstrate the potential of slow steaming. In addition, the often ignored costs for lubricating oil were incorporated. Based on a more detailed analysis, an enormous potential of cost savings for shipping companies became apparent and better documented.

Environmental aspects were mentioned but this paper is not focused on them. Without any doubt, environmental aspects demand significant attention in future research, in particular considering IMO

regulations and pressure to comply with governmental rules striving for environmental friendly shipping.

The increased tie-up of shipping capacity as a result of slow steaming was briefly discussed as well. In times of significant overcapacity, this tie-up and the resulting increase of freight rates is a positive effect on the market. Contrary, in times of demand exceeding supply, the additional removal of transport capacity by slow steaming is disadvantageous for shipping companies since they lose income. For customers, longer trip duration is disadvantageous due to their tied-up capital being shipped. This has to be considered as a comparative disadvantage for shipping companies in a highly competitive market.

For giving an advice from an economic point of view, the composition of profit was analyzed. Slow steaming affects costs as well as revenue. The deducted profit function delivered the formula for the profit optimizing speed. An exemplary calculation illustrated the findings. The presented considerations can be helpful for calculating an optimum speed. However, real world operation is even more complex. As in aviation, exogenous variables such as weather conditions have significant impact on fuel consumption. The current version of our paper, like other sources in the maritime economics literature, provides no consideration of the potentially significant effects of such exogenous variables. Taking a ship's characteristics and (forecasts of) weather and sea conditions into account is the focus of 'ship weather routing' approaches aiming at the calculation of a track for ocean voyages resulting in, e.g., maximum safety and crew comfort, minimum fuel consumption, minimum time underway, or any desired combination of these factors (see, e.g., basic work in [18, 19, 20]). If one has to take into account weather effects this could dramatically change the modeling emphasis from a static planning perspective to a dynamic, online optimization application. When approaching a decision support system (DSS) for the container shipping industry this is an issue of future research, especially when combining this with fleet deployment issues. For example, a DSS should reflect the main influencing technical and economical factors, such as vessel characteristics, freight rates, emissions, weather conditions, trim, etc., and goals, such as cost or emission minimization or profit maximization. The DSS can result in better decisions on operating a ship during a specific voyage (speed, route), in particular if a sensitivity analysis is provided for a better estimate of decision impacts in an environment with uncertain events.

The most important question regarding slow steaming aims at its sustainability. The demonstrated calculations show that the optimal vessel speed mainly

depends on freight rates and fuel prices. Hence, a decreased speed is reasonable in particular in times with high fuel prices and low freight rates. Assuming, that fuel prices will not significantly drop in the near future, it can be concluded that from an economical perspective slow steaming is a good if not the best operating mode for container vessels. However, there are technical issues. For example, the lifespan of an engine is expected to decrease due to suboptimal usage. Therefore, engine manufacturers offer, e.g., 'slow steaming kits' in order to overcome such problems (see, e.g., [34, 35]). These preparations require additional investments that should be incorporated into calculations and cost-benefit analyses, e.g., in a lifecycle costing approach.

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