

Evaluating the effects of speed reduce for shipping costs and CO₂ emission[☆]



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ABSTRACT

Global greenhouse gas emissions have driven up carbon dioxide levels beyond 400 parts per million, thereby increasing the rate of global warming. This paper conducted a thorough assessment of available operating strategies to identify the approach to speed reduction that is best able to minimize costs and reduce the impact of shipping on the environment. Our results indicate that optimum speed reduction is a dynamic process depending largely on charter rates and fuel prices. The significant cost advantages afforded by this approach could improve the competitiveness of ship operators.

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Introduction

In 2013, the National Oceanic and Atmospheric Administration (NOAA) reported that atmospheric carbon dioxide (CO₂) levels exceeded 400 parts per million, demonstrating a clear failure to meet the goals of the Kyoto Protocol. Approximately 3 per cent of global CO₂ emissions are produced by international shipping fleets, which are not covered by the international regulatory framework under the Kyoto Protocol or the Copenhagen Accord (UNCTAD, 2010). This is due to the considerable difficulties involved in mitigating these emissions through legislation. In addition, ship operators have been given very few practical alternatives with which to reduce emissions.

Researchers have demonstrated that slow steaming or speed reduction can significantly reduce fuel consumption and resulting emissions reduction (Corbett et al., 2009). The Second IMO GHG Study in 2009 presented evidence that such savings could be in the range of ~23 per cent. CE Delft (2010) presented slow-steaming as a viable option to reduce emissions in depressed markets. In contrast, Lindstad et al. (2013) assessed the effectiveness of speed reductions under various sea conditions and freight markets and discovered considerable benefits with regard to cost and emissions in a good freight market. Cariou (2011) discovered that when fuel prices rise to \$350–\$400 USD per metric ton, container ships could reduce their speed in long distance runs in order to cut fuel costs. Psaraftis and Kontovas (2010) argued that speed reductions would lead to a loss of revenue and increase transit times resulting in the need for additional ships to meet demand (UNCTAD, 2012). These conflicting results have led to fierce debate. The aim of this paper was to develop a model with which to identify the optimum speed reduction strategy capable of minimizing costs and mitigate CO₂ emission. A wide range of factors were included in the model, including revenue loss, increased transit times, and fuel costs. Evidence based on data from actual

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operations suggests the economic benefits of these measures could convince ship operators to adopt this strategy, which would ultimately help to mitigate carbon dioxide levels in the Earth's atmosphere.

Estimation methodology

Effect of speed reduction function and optimum speed reduction

This study focused on the use of ship speed management to reduce the costs in short-term voyages. The proposed model was used to assess variations in costs (C) before and after speed reduction (S_i), which also influenced the revenue; E denotes the function of revenue generation referred to by speed reduction:

$$E = f(C, S_i) \quad (1)$$

The effects of varying degrees of speed reduction can be evaluated, to obtain a speed reduction effects curve. Speed reduction reduces fuel consumption but also lengthens the duration of the voyage. The revenue and costs influenced by speed reduction are outlined in Table 1. An extended voyage results in opportunity costs, increased operation costs, and speed reduction reduced fuel consumption. Therefore, the calculation must include variations in these three factors.

To evaluate the influence of speed reduction, we must first calculate the delays and then the differences in revenue, which involves deducting the increased operation costs, opportunity costs, and the reduced fuel costs from the fuel savings. It is assumed in the calculations that the ship works under the same circumstances, such as the same conditions at sea, the same lease or other contract terms, and the same shipping course. The calculations were conducted with voyage as the unit. E can be written as

$$\begin{aligned} E_i &= \Delta F - \Delta OP - OT = (F_o - F_r) - T_d \times OP - T_d \times TC \\ &= (\Delta MF + \Delta AF) - T_d \times (OP + TC) \end{aligned} \quad (2)$$

where E_i is effects of speed reducing to i knots, ΔF denotes the difference in fuel costs before speed reduction (F_o) and after speed reduction (F_r); ΔOP signifies the difference in operation costs equal to the delay of arrival in days multiplied by daily operating costs (OP); OT indicates opportunity costs, which equals the delay of arrival in days multiplied by daily lease fees; MF and AF are the fuels costs of the main and auxiliary engines, respectively. A positive value for the increase in revenue due to speed reduction would indicate that speed reduction is effective way to reduce costs and pollution, whereas a negative result would mean that speed reduction is inefficiency.

Stopford (2009) and Corbett et al. (2009) suggested that the cubic rule be applied to the calculation of fuel consumption as it pertains to reductions in speed:

$$F_r = MF^* \times \left(\frac{S^r}{S^*} \right)^3 \times FP_{mf} + AF^* (1 + T_d) \times FP_{af} \quad (3)$$

In the above formula, MF^* and AF^* denote the fuel consumption of the main engine and auxiliary engine at the design speed; S^r is the speed after reduction; S^* is the design speed, FP_{mf} is the price of fuel (\$/metric ton) used in the main engine, and FP_{af} is the price of fuel (\$/metric ton) used in the auxiliary engine.

A reduction in speed would increase sailing times, which would mean that ship owners incur higher capital costs, maintenance expenses, wages for the crew, and insurance. These expenses would then be passed on to those chartering the ships. Shipping delay caused by speed reduction is an import decision variable, which can be calculated according to the speed and distance of the voyage, as follows:

$$T_d = \left(\frac{d_{ij}}{24S^r} \right) - \left(\frac{d_{ij}}{24S^*} \right) \quad (4)$$

where d signifies the distance between the port i and port j .

Table 1
Effects of speed reduction on revenue and costs.

Item (unit)	Classify	Effect
Revenue (\$/voyage)	Cargo loaded $\times$ Freight rate	Speed reduction delays the time at which a ship arrives at its destination, resulting in the loss of opportunity to transport other cargo
Cost	Operation costs (\$/day)	Crew wages, Storage, Lubricants, Repairs, Maintenance, Insurance, Administration, Capital cost
	Voyage costs (\$/voyage)	Main engine fuel cost
		Auxiliary engine fuel cost
		Cargo handling cost, Port change, Canal dues Tugs, etc.
		Speed reduction increases transport time and therefore increases operating costs (including crew wages, maintenance fees, and capital costs)
		Speed reduction reduces fuel consumption in the main engine and therefore reduces fuel costs
		Extending the transport time increases the operation time of the auxiliary engine, thereby increasing fuel consumption
		No influence

Based on Eq. (3) and Eq. (4), the Eq. (2) can be reformulated as Eq. (5):

$$E_i = \left((MF_o \times FP_{mf} + AF_o \times FP_{df}) - (MF_o \times \left(\frac{S^r}{S^*}\right)^3 \times FP_{mf} + AF_o(1 + T_d) \times FP_{df}) \right) - \left(\left(\left(\frac{d}{24S^r} \right) - \left(\frac{d}{24S^*} \right) \right) \times (OP + TC) \right) \quad (5)$$

$$\text{Subject to} \quad \frac{S^r}{S^*} \leq 1, T_d \geq 0$$

From the speed reduction effects curve, we can identify the maximum cost-benefit from speed reduction as well as the optimal ship speed after reduction, calculated using Eq. (6):

$$\text{Max}(E) = \text{Max}(\Delta MF) - \Delta AF - \Delta OP - \Delta TC \quad (6)$$

where optimal speed reduction is dynamic, as reported by [Clarksons \(2010\)](#); profit optimization can also be achieved via speed adjustments based on fuel prices and freight rates. Optimal speed reduction also improves profit and reduced gas emissions from fuel consumption, thereby benefiting both the operators as well as the environment.

Emissions following optimum speed reduction

[Psaraftis and Kontovas \(2013\)](#) calculated the CO₂ emissions of ship engines using the following emission factors: 3.082 kg CO₂/ton for marine diesel and marine gas oils and 3.021 kg CO₂/ton for heavy fuel oils. The following formula illustrates the effects of reducing speeds on ship emissions:

$$\begin{aligned} \Delta EM &= \Delta MF_c \cdot EF_{hf} + \Delta AF_c \cdot EF_{df} \\ &= \left((MF_o \times EF_{hf} + AF_o \times EF_{df}) - (MF_o \times \left(\frac{S^r}{S^*}\right)^3 \times EF_{hf} + AF_o(1 + T_d) \times EF_{df}) \right) \end{aligned} \quad (7)$$

where ΔEM is the difference between CO₂ emissions before and after speed reduction; ΔMF_c and ΔAF_c denote the differences in fuel consumption in the main engine and the auxiliary engine, respectively, and EF_{hf} and EF_{df} are the CO₂ emissions coefficients of the main engine and the auxiliary engine during the voyage at sea.

Empirical results and discussion

Data sources

Calculations for the speed reduction effect and reduction in emissions were determined using seven vessels found in the Clarkson Research Shipping Intelligence Network database. [Table 2](#) lists the time charter rates and fuel prices for the period from 2000 to 2013. These values are based on a modified estimation method, in which fuel costs vary with fuel consumption and prices. The distance of the voyage was set at 1600 nautical miles and the effect was calculated according to Eq. (5).

Assessment of optimum speed reduction

To maximize the speed reduction profit, this study determined the optimum speed reduction for four scenarios based on ship speed, fuel prices, and time charter rates.

Table 2
Characteristics of vessels.

Vessel type	Size (dwt)	Speed (Knots)	Daily fuel consumption at sea (M.T/day)		Time charter Rate (US\$/day)	
			Main engine (IFO = 380 Cst)	Auxiliary engine (MDO)	Max (High)	Min (Low)
Capesize bulk	150,000	14	50.8	1.5	137,200	9500
Handysize bulk	30,000	14.05	24.75	0.5	40,800	6000
VLCC	310,000	16	96.8	1.8	90,000	19,563
Handysize tanker	48,000	15	40.3	1.1	30,500	11,875
Panamax container	3604 teu	20.5	74	1.2	40,000	4500
Sub-Panamax container	2750 teu	18.8	47.5	1.2	32,500	4200
Handysize container	1700 teu	21.2	65	0.8	44,000	5450
High bunker price		IFO = \$680 pmt		MDO = \$1130 pmt		
Low bunker price		IFO = \$102 pmt		MDO = \$148 pmt		

Source: Clarksons Research LTD.

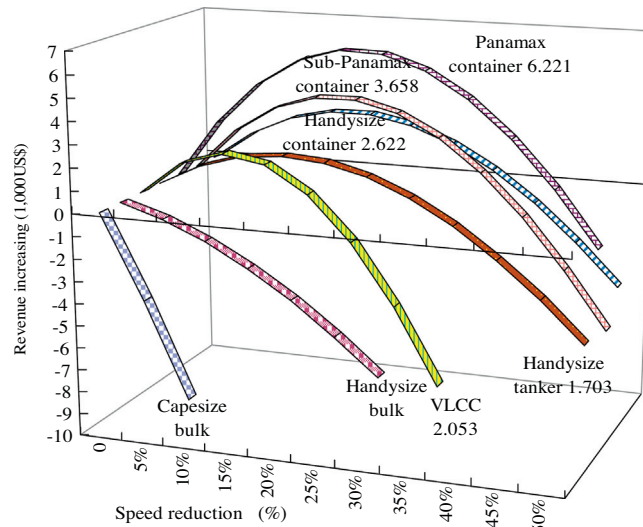


Fig. 1. Effect of speed reduction under scenario 1.

Scenario 1: High fuel prices and high charter rates (HFHR)

As shown in Fig. 1, the optimum reduction in speed resulted in a daily maximum cost-benefit of between \$ 1703 to \$6221 USD for tanker and container ships; however, no benefit was observed for bulk ships.

Scenario 2: High fuel prices and low charter rates (HFLR)

As shown in Fig. 2, reducing speeds provide benefits for all types of ship; the optimum speed reduction resulted in a daily maximum cost-benefit of between \$16,980 and \$17,150 USD for Sub-Panamax containers and VLCC.

Scenario 3: Low fuel prices and high charter rates (LFHR)

As shown in Fig. 3, reducing speeds did not provide benefits for any type of ship. This result is the same as presented by Psaraftis and Kontovas (2013).

Scenario 4: Low fuel prices and low charter rates (LFLR)

As shown in Fig. 4, speed reduction resulted in slight benefits for container ships but a considerable loss in revenue for bulk and tanker ships.

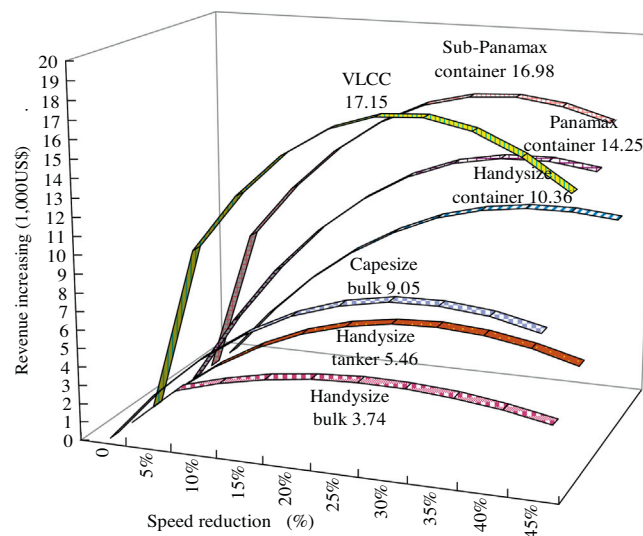


Fig. 2. Effect of speed reduction under scenario 2.

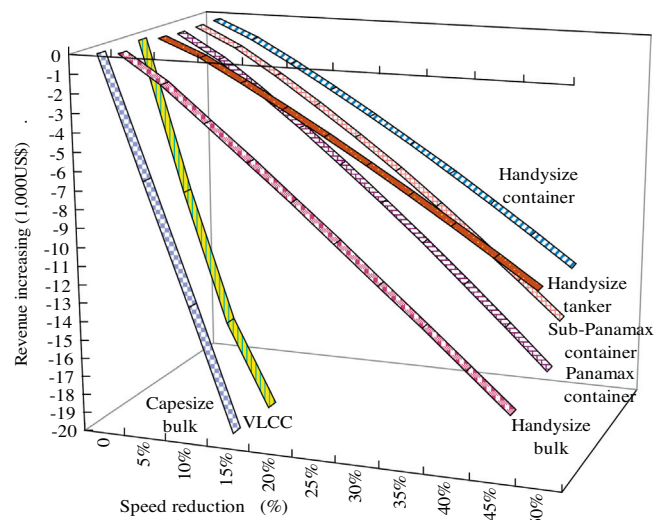


Fig. 3. Effects of speed reduction under scenario 3.

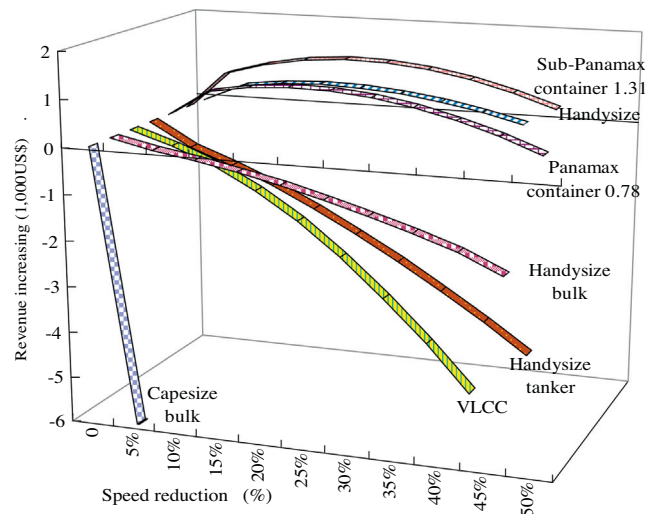


Fig. 4. Effects of speed reduction under scenario 4.

The differences between these scenarios illustrate the relationship between fuel prices and time charter rates for various types of ship according to speed reduction.

Summary

Table 3 presents a summary of the results obtained from an optimum reduction in speed with regard to CO₂ emissions and the cost savings enjoyed by operators in four typical situations. In scenario 2, shipping industry is face an oversupply and high fuels price situation. In determining operating speeds, ship operators try to balance fuel costs with journey times.

In practice, the cost advantages afforded by speed reduction are in the range of 20–30%, depending on the age of the vessel and engine and hull condition (Stopford, 2009). Speed optimization is meant to reduce fuel costs as well as reduce carbon emissions. Applying this strategy to the management of fleets in order to improve efficiency can only be achieved by taking into account the characteristics of each ship. At present, the shipping industry faces an oversupply of ships, such that bulk operators adjust speeds according to economic concerns regarding the balance between fuel costs and journey times. In this situation, there is no need to use more vessels. The fact is that the service speed of container ships is determined by sailing schedules agreed upon or stipulated by charter parties or operators. Ships traveling in emissions control areas (ECA) will have to use low sulfur fuel and/or moderate speeds to reduce fuel consumption and emissions but enforcing these restrictions is difficult to achieve in practice.

Table 3

Results of optimum speed reduction under four scenarios.

Item of scenario		Bulk		Tanker		Container		
		Capesize	Handysize	VLCC	Handysize	Panamax	S-Panamax	Handysize
Scenario 1 (HFHR)	Optimum speed	nil	nil	15.3	13.6	16.96	15.4	15.04
	Max daily cost-benefit	0	0	2053	1703	3658	6172	2622
	CO ₂ reduction	0	0	19%	26.6%	34.9%	42.5%	34.9%
Scenario 2 (HFLR)	Optimum speed	8.28	8.58	9.35	9.6	8.46	8.2	8.46
	Max daily cost-benefit	8214	3510	15,533	4618	14,250	13,394	8784
	CO ₂ reduction	65.4%	61.3%	69.8%	60.5%	77.6%	80.3%	76.4%
Scenario 3 (LFHR)	Optimum speed	nil	nil	nil	nil	nil	nil	nil
	Max daily cost-benefit	0	0	0	0	0	0	0
	CO ₂ reduction	0	0	0	0	0	0	0
Scenario 4 (LFLR)	Optimum speed	nil	nil	nil	nil	15.9	13.94	14.3
	Max daily cost-benefit	0	0	0	0	1262	1262	518
	CO ₂ reduction	0	0	0	0	42.4%	52.4%	41%

Conclusions

This study comparing the total expected cost of speed reduction against the total expected benefits, to see whether the cost-benefit, and presented four scenarios to illustrate the effects of speed reduction on operational efficiency. When considering the impact of fuel costs on the revenue generated by ships, it is crucial for ship operators to have an effective means with which to identify the optimum reduction in speed. In this study, the optimum results were obtained under scenario 2, in which fuel costs were high and charter rates were low. Our results indicate that attaining the optimum speed reduction is a dynamic process depending largely on charter rates and fuel prices. The benefits in cost savings afforded by a reduction in shipping speeds should be sufficient to encourage shippers to voluntarily implement such measures without the need for governmental intervention.

Selecting the optimum ship speed is a dynamic process of balancing benefits against losses. The first stage involves determining the optimal tradeoff between fuel costs and the costs resulting from time delays. This is followed by the fine adjustment of engine speeds and ensuring that the engines are capable of running efficiently for long durations at reduced output levels. Finally, shippers must ensure that the adjusted speeds are sufficient to meet demand in order to avoid having to schedule additional vessels. Alliances with other shipping companies could also be pursued in order to compensate for the loss of trade.

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