SPEED REDUCTION AS AN EMISSIONS REDUCTION MEASURE FOR FAST SHIPS

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ABSTRACT

Ships that sail at high speeds emit a higher amount of air emissions on a per tonne-km basis than ships that go slower. As the goal of environment-friendly shipping is high on the agenda of the IMO, the European Commission and many individual coastal states, reduction of emissions, both from greenhouse gases (GHG) such as CO_2 , and also from SOx, NOx , and other gases, is an important and urgent target. One of the obvious operational measures that is contemplated to reduce emissions is speed reduction. As there is a cube law between speed and fuel consumption per day, the higher a ship's speed is, the more her emissions can be reduced by speed reduction. This is particularly true for high speed craft but also for containerships, RoPax ferries and other ships that go faster than the average. However, a reduction in speed may have undesirable side-effects that may generally entail non-trivial costs. Such side-effects may include the need for more ships in the fleet, increased cargo inventory costs, and others, and collectively may render speed reduction not necessarily cost-effective. Alternatively, one may compensate by reducing port time, to the extent possible. This paper investigates such issues for a variety of ship types at the higher end of the speed spectrum and attempts to identify factors that are important and alternatives that are more cost-effective.

1. INTRODUCTION

Emissions from commercial shipping are currently the subject of intense scrutiny by the world shipping community and society at large. According to the Kyoto protocol definite measures to reduce CO_2 emissions are necessary in order to curb the projected growth of greenhouse gases (GHGs) worldwide. Shipping has thus far escaped being included in the Kyoto global emissions reduction target for CO_2 and other GHGs. But it is clear that the time of non-regulation is rapidly approaching its end, and measures to curb future CO_2 growth are being sought with a high sense of urgency. CO_2 is the most prevalent of these GHGs, and it is therefore clear that any set of measures to reduce the latter should primarily focus on CO_2. Various analyses of many aspects of the problem have been and are being carried out and a spectrum of measures are being contemplated.

At the 58th session of the IMO's Marine Environment Protection Committee (MEPC 58), held in London in October 2008, progress as regards air pollution from ships was mixed. First of all, the IMO unanimously adopted amendments to the MARPOL Annex VI regulations. The main changes will see a progressive reduction in sulphur oxide (SO_x) emissions from ships, with the global sulphur cap reduced initially to 3.50%, effective 1 January 2012; then progressively to 0.50%, effective 1 January 2020 (IMO, 2008a).

Furthermore, the report of Phase 1 of the update the 2000 IMO GHG Study (IMO, 2000) was presented, which was conducted by an international consortium led by Marintek, Norway (Buhaug, et al 2008). According to the results of Phase 1, the three most fuel consuming categories of ships (and thus, those that produce most of CO_2 emissions) are Container vessels of 3,000-5,000 TEUs, Container vessels of 5,000-8,000 TEUs and RoPax Ferries with cruising speed of less than 25 knots (see Table 30 in Buhaug, et al (2008) that presents a summary of results from consensus estimate fuel oil consumption calculations). The answer to why these three categories produce that huge amount of CO_2 emissions is not the large number of ships – obviously not for the case of container vessels. Their common denominator is their high speed.

These findings are in line with those of Psaraftis and Kontovas (2008, 2009a). According to their analysis, containerships are the top CO_2 emissions producer in the world fleet (2007, Lloyds-Fairplay database). Just the top tier category of container vessels (those of 4,400 TEU and above) are seen to produce CO_2 emissions comparable on an absolute scale to that produced by the entire crude oil tanker fleet (in fact, the emissions of that top tier alone are slightly higher than those of all crude oil tankers combined- see Fig. 1 below).

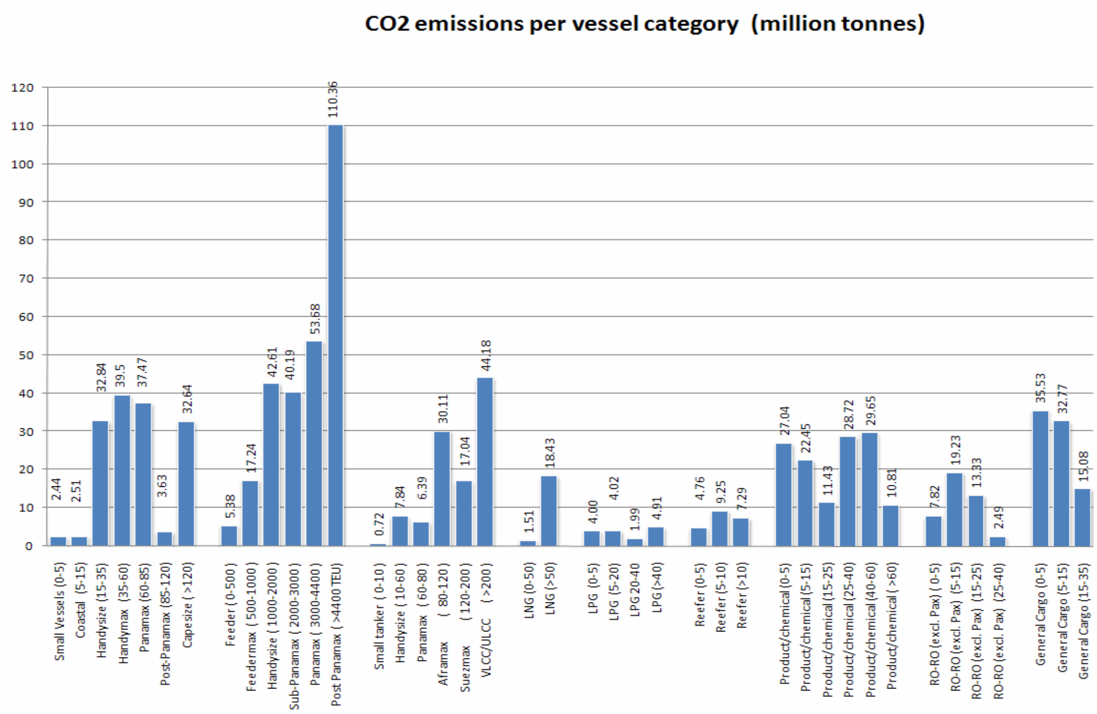


Fig. 1. CO_2 emissions, world fleet (Psaraftis and Kontovas, 2009a)

It is also interesting to point out that the European Commission is following IMO developments very closely and has stated very clearly its intention to act alone if IMO's procedures take longer than previously anticipated. Currently, European legislation mainly concerns the sulphur content of marine fuels. The maximum sulphur content for marine fuels according to EU directive 2005/33/EC is in line with MARPOL Annex VI. The implementation dates are differently from those agreed by the IMO under MARPOL Annex VI, but the main point is that currently all vessels sailing in the designated areas (Sulphur Emission Control Areas, also known as SECAs) such as Baltic Sea,Northern Sea should use marine fuels with a maximum of 1.5% by mass content of sulphur. What is different from MARPOL is that the EU Directive sets a limit for all passenger vessels operating on regular service to or from EU ports to a maximum sulphur content of 1.5 % (the same as in SECAs).This limit came into effect on August 11th, 2006 (EU directive 2005/33/EC, Article 4a). Furthermore, according to Article 4b of the same Directive, from January 1st, 2010 a 0.1% limit comes into effect for inland waterway vessels and ships at berth in EU ports with some exemptions.

In a general sense, the drive to reduce emissions entails a broad spectrum of measures. Some of these measures are technical, and some are operational. In this paper we shall focus on the operational ones and namely on speed reduction measures that have a direct link to logistical operations, and investigate related tradeoffs The reason for investigating such tradeoffs is that measures to reduce such emissions may possibly have ramifications as regards the logistical supply chain, and vice-versa. Industry circles have also voiced the concern that low-sulphur fuel in SECAs may make maritime transport (and in particular short-sea shipping) more expensive and induce shippers to use land-based alternatives even though shifting cargo from land to sea is an important policy goal. A reverse shift of cargo from sea to land might increase the overall level of CO_2 emissions along the intermodal chain.

Before we proceed with our analysis, we first note that even though the literature on the broad area of this paper (ship emissions) is immense, the literature on the specific topic of this paper is scant. There are however a number of papers that consider the economic impact of speed reduction especially for container vessels. Andersson (2008) considered the case of a container line where the speed for each ship reduced from 26 knots to 23 knots and one more ship was added to maintain the same throughput. Total costs per container were reduced by nearly 28 per cent. Eefsen (2008) considered the economic impact of speed reduction of containerships and included the inventory cost. Cerup-Simonsen (2008) developed a simplified cost model to demonstrate how an existing ship could reduce its fuel consumption by a speed reduction in low and high markets to maximize profits. Corbett et al. (2009) applied fundamental equations relating speed, energy consumption, and the total cost to evaluate the impact of speed reduction.

The rest of this paper is organized as follows: The section that follows deals with the algebra of CO_2 emissions and the related fuel costs. The following two investigate the effect of speed reduction for containerships and RoPax ferries. The final section presents the paper's conclusions.

2. ALGEBRA OF EMISSIONS AND FUEL COSTS

2.1 Emissions and fuel costs per trip

Our simplest scenario to investigate the impact of speed reduction on ship CO_2 emissions and on other attributes of the ship operation assumes that a known ship loads from a port A, travels to port B (a total distance of L nm from A) carrying a payload W with a known speed of V_0 (in knots), where she discharges the cargo and stays idle before departing again.

Assume that the daily fuel consumptions and times that the ship spends at sea and in port are known and are as follows:

<u>At sea:</u>

Fuel consumption F_0 (tonnes per day)

Total time at sea $T_0 = \frac{L}{24 \cdot V_0}$ (days)

<u>In port:</u>

Fuel consumption f (tonnes per day)

Total time in port t_0 (days)

Thus, the total fuel consumption for this trip is $FC_0 = F_0 \cdot T_0 + f \cdot t_0$

Now suppose that the ship operator wants to investigate the scenario of speed reduction. This may be for cost-related reasons (such as the increased fuel prices in a volatile fuel market or the increased fuel price for low sulphur marine fuel), or for environmental reasons (to decrease CO_2 emissions), or for both.

The new speed V will be a fraction of the original speed ($V = aV_0$ where $0<a<1$) and hence there will be an increase of the time at sea, $T = \frac{L}{24V} = \frac{To}{a}$

Realistic values for the speed reduction factor 'a' can be in the range of 0.8 to 0.95, which imply a speed reduction in the range of 5 to 20 per cent. The effect of speed change on fuel consumption is assumed cubic for the same ship (and for speeds that are close to the original speed), that is, the fuel consumption at the reduced speed F can be estimated as follows:

$$\frac{F}{Fo} = \left(\frac{V}{Vo}\right)^3$$ given that $F_0=kV_0^3$, where k is a known constant.

Fuel consumption in port per day will remain the same, but we assume that the new time in port (t) will be reduced in order to keep at least the same total trip time with that before the speed reduction.

For this trip we can compute the difference in fuel consumption as follows:

$$\Delta(\text{Fuel Consumption})=\Delta(\text{consumption at sea}) + \Delta(\text{consumption at port})$$

$$=F\cdot T\text{-}F_0\cdot T_0+f\cdot t\text{-}f\cdot t_0=F\cdot\frac{L}{24\cdot V}\text{-}F_0\cdot\frac{L}{24\cdot V_0}+f\cdot(t\text{-}t_0)=$$

$$\overset{V=aV_0}{=}F\cdot\frac{L}{24\cdot aV_0}\text{-}F_0\cdot\frac{L}{24\cdot V_0}+f\cdot(t\text{-}t_0)=\frac{L}{24\cdot V_0}\left(F\cdot\frac{1}{a}\text{-}F_0\right)+f\cdot(t\text{-}t_0)=$$

$$\overset{\frac{F}{F_0}=\left(\frac{V}{V_0}\right)^3}{=}\frac{L}{24\cdot V_0}\left(\left(\frac{V}{V_0}\right)^3F_0\cdot\frac{1}{a}\text{-}F_0\right)+f\cdot(t\text{-}t_0)=\frac{L}{24\cdot V_0}\left(\left(\frac{aV_0}{V_0}\right)^3F_0\cdot\frac{1}{a}\text{-}F_0\right)+f\cdot(t\text{-}t_0)=$$

$$=\frac{L}{24\cdot V_0}\left(a^3F_0\cdot\frac{1}{a}\text{-}F_0\right)+f\cdot(t\text{-}t_0)$$

Thus, total fuel consumption for slow steaming is:

$$\Delta(\text{Fuel Consumption})=\frac{L}{24\cdot V_0}F_0\left(a^2\text{-}1\right)+f\cdot(t\text{-}t_0) \qquad \text{(1a)}$$

As one may notice, the first addend is negative since, by definition, parameter 'a' lies between 0 and 1 and L, F_0 and V_0 are always positive. It is obvious that if time in port remains the same ($t\text{-}t_0$ equal to 0) there will be a need to add a number of additional vessels (possibly fractional) in order to maintain the same throughput per year. For an analysis of related scenarios see Psaraftis and Kontovas (2009c). The present paper examines alternative scenarios, by assuming that $t < t_0$, and in fact that 't' is such that the total trip time, including time in port, remains the same $(T+t=T_0+t_0)$.

It should be realized of course that reducing port time may not be possible, as this would depend on a variety of factors that may concern either the ship, or the port itself, or both. But if time in port can be reduced at all, it can be a crucial factor to reducing ship total emissions. To our knowledge, this has not been investigated much in the literature.

Reduction of port time would depend on factors that include, among others,

- Allocating more cargo handling resources to the ship being served (mostly for container vessels)
- Existence of slack time in a ship's schedule (mostly for Ropax vessels)
- Expanding port infrastructure so that more ships can be handled without waiting (for all ships).

In all such cases a decrease in port time leads to a negative $t\text{-}t_0$ and, thus, according to (1a), speed reduction leads to a decrease in fuel consumption per roundtrip and, consequently, per year.

CO_2 emissions reduction

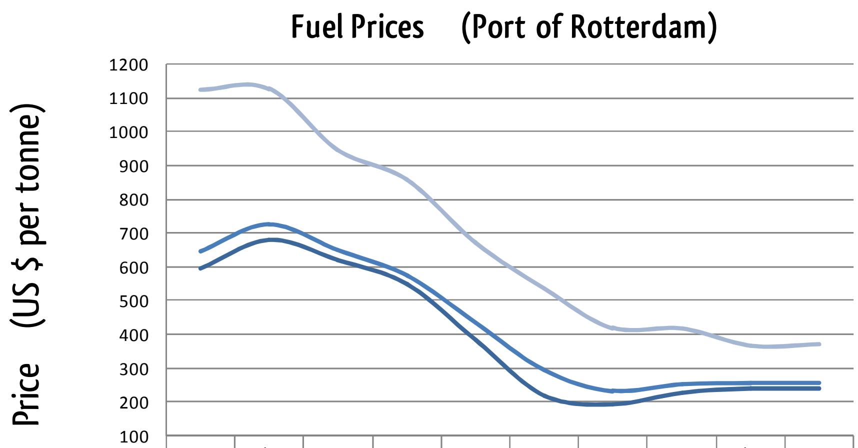
To find the equivalent CO_2 emissions reduction, one has to multiply the reduction in bunker consumption by an appropriate emissions factor (F_{CO_2}). The 3.17 CO_2 emissions factor has been the empirical mean value most commonly used in CO_2 emissions calculations based on fuel consumption (see EMEP/CORINAIR (2002) and Endresen (2007)). According to the IMO GHG study (IMO, 2000), the actual value of this coefficient may range from 3.159 (low value) to 3.175 (high value). The update of the IMO 2000 study (Buhaug et al,2008), which has been presented at MEPC 58, uses slightly lower coefficients, different for Heavy Fuel Oil and for Marine Diesel Oil. The actual values are 3.082 for Marine Diesel and Marine Gas Oils (MDO/MGO) and 3.021 for Heavy Fuel Oils (HFO). According to the report of the Working Group on Greenhouse Gas Emissions from Ships (IMO, 2008b), the group agreed that the Carbon to CO_2 conversion factors used by the IMO should correspond to the factors used by IPCC (2006 IPCC Guidelines) in order to ensure harmonization of the emissions factor used by parties under the UNFCCC and the Kyoto Protocol. In this paper we use the 3.13 value to ensure this harmonization.

Table 1. Comparison of Emission Factors kg CO2/kg Fuel. (IMO, 2008b)

FUEL TYPE	GHG-WG 1/3/1	IPCC 2006 Guidelines			Revised 1996 Guidelines
		Default	Lower[b]	Upper[b]	
Marine diesel and marine gas oils (MDO/MGO)	3.082	3.19	3.01	3.24	3.212[a]
Low Sulphur Fuel Oils (LSFO)	3.075	3.13	3.00	3.29	
High Sulphur Fuel Oils (HSFO)	3.021				

Reduction in fuel costs

The fuel cost reduction can be estimated by assuming that the price of the fuel used by the ship is known and equal to p (assumed constant during the year). Even though it is assumed a constant in our analysis, p is very much market-related, and, as such, may fluctuate widely in time, as historical experience has shown (see Figure 1). This assumption causes no loss of generality, as an average price can be used. Also, as the ship will generally consume different kinds of fuels during the trip and in port assuming a unique fuel price is obviously a simplification. But this causes no loss of generality either, as an average price can be assumed for the general case.



	Jun 08	Jul 08	Aug 08	Sep 08	Oct 08	Nov 08	Dec 08	Jan 09	Feb 09	Mar 09
IFO 380 (max 4.5% s)	597.5	680.5	622.5	549.5	384.0	221.0	193.5	229.5	240.0	241.5
LS 380 (max 1.5% s)	644.5	728.0	649.0	574.5	436.5	293.5	233.0	252.5	255.5	255.5
MDO (max 0.5% s)	1126.0	1127.5	948.0	857.5	670.5	536.5	420.0	417.5	368.5	372.5

Fig. 2. Average Monthly Fuel Oil Prices (from www.bunkerworld.com)

To sum up, before the speed reduction, total fuel consumption was $FC_0=F_0 \cdot T_0 + f \cdot t_0$, representing a total cost of $TC_0=p \cdot FC_0$ and corresponding to $TEmis_0=F_{CO_2} \cdot FC_0$ CO_2 emissions.

Given the above we can now estimate the reduction in fuel costs and in CO2 emissions as follows:

Fuel costs reduction:

$$\Delta(\text{fuel costs})=p \cdot \left[\frac{L}{24 \cdot V_0} F_0 \left(a^2-1\right) + f \cdot \left(t-t_0\right) \right] \tag{2a}$$

CO_2 emissions reduction (absolute and per unit of transport work):

$$\Delta(CO_2 \text{ emissions})=F_{CO_2} \cdot \left[\frac{L}{24 \cdot V_0} F_0 \left(a^2-1\right) + f \cdot \left(t-t_0\right) \right] \tag{3a}$$

$$\Delta(\text{gr } CO_2 \text{ per transport work})=\frac{F_{CO_2} \cdot \left[\frac{L}{24 \cdot V_0} F_0 \left(a^2-1\right) + f \cdot \left(t-t_0\right) \right]}{\text{transport work}} \tag{4a}$$

Transport work is the product of the transported cargo W and the distance traveled L. Distance L is measured in nautical miles (nm). The units of W, however, depend on the ship type and are generally measured in tonnes, except for the cases of containerships, pure car carriers (Ro-Ro), and cruise vessels, where TEUs (twenty feet equivalent units), cars and passengers are used respectively. In RoPax vessels a mixture of units can be used, for both passengers and vehicles.

The ratio in equation 4a reminisces the CO_2 operational index, also known as the energy efficiency index, extensively discussed at the IMO. As the latter index is defined today (see the Interim Guidelines for Voluntary Ship CO_2 Emission Indexing, IMO(2005)) the operator of RoPax vessels can choose between passengers, car units, occupied lane-meters or another singular unit expressing amount of cargo transported. Thus, ferries currently report transport work either as passenger miles or car unit miles.

2.2 Emissions and fuel costs on an annual basis

In a similar way we can estimate the reduction in fuel costs and emissions on a per year basis. Now our approach is more generic and does not depend on the way that the ship operates. It is only necessary that we know the total time that the ship spends at sea per year and in port, as well as the total distance traveled. We also assume that the ship sails at a constant speed of V.

Furthermore, assume that ship's operational days per year are D ($0<D<365$), a known input, and that the average daily fuel consumptions (in tonnes per day) and times that she spends at sea and in port (in days per year) are known and are as follows:

At sea: Fuel consumption F_0 (tonnes per day) and total time at sea T_0^*

In port: Fuel consumption f (tonnes per day) and total time t_0^*

Note that the daily fuel consumptions on a yearly basis are assumed to be the same as on a per trip basis and thus constant per each leg. There is, however, no loss in generality since we could extend our approach by assuming an average daily fuel consumption.

In this case total fuel consumption is $FC_0^*=F_0 \cdot T_0^* + f \cdot t_0^*$, representing a total cost of $TC_0^*=p \cdot FC_0^*$ and corresponding to $TEmis_0^*=F_{CO_2} \cdot FC_0^*$ CO_2 emissions.

Suppose now that we want to investigate the scenario of speed reduction. Exactly as assumed before, the new speed V will be a fraction of the original speed ($V=aV_0$ where $0<a<1$) and hence there will be an increase on the total time at sea per year, let us call it T*. The effect of speed change on fuel consumption is assumed again cubic and the fuel consumption at the reduced speed F can be estimated as follows:

$$\frac{F}{Fo}=\left(\frac{V}{Vo}\right)^3$$ given that $F_0=kV_0^3$, where k is a known constant.

Once again, consumption in port per day will remain the same but we assume that the total time in port , t_0^*, will be reduced in order to maintain the same total time as before.

We can now compute the difference in fuel consumption in the same way as we did before and, thus, after some simple algebraic manipulations:

$$\Delta(Fuel\ Consumption)=\Delta(consumption\ at\ sea) + \Delta(consumption\ at\ port)$$

$$=F \cdot T^* - F_0 \cdot T_0^* + f \cdot t^* - f \cdot t_0^* = F \cdot \frac{L^*}{24 \cdot V} - F_0 \cdot \frac{L^*}{24 \cdot V_0} + f \cdot \left(t^* - t_0^*\right) =$$

$$= \frac{L^*}{24 \cdot V_0}\left(a^3 F_0 \cdot \frac{1}{a} - F_0\right) + f \cdot \left(t^* - t_0^*\right)$$

Finally, fuel consumption reduction for slow steaming on a per year basis is:

$$\Delta(Fuel\ Consumption)=T_0^* \cdot F_0\left(a^2-1\right)+f \cdot \left(t^*-t_0^*\right) \quad (1b)$$

where $T_0^* = \frac{L^*}{24 \cdot V_0}$

Similarly, Fuel costs reduction:

$$\Delta(fuel\ costs)=p \cdot \left[T_0^* \cdot F_0\left(a^2-1\right)+f \cdot \left(t^*-t_0^*\right)\right] \quad (2b)$$

CO_2 emissions reduction :

$$\Delta(CO_2\ emissions)=F_{CO_2} \cdot \left[T_0^* \cdot F_0\left(a^2-1\right)+f \cdot \left(t^*-t_0^*\right)\right] \quad (3b)$$

Note that he above equations could be further simplified given the fact that the ship owner should ensure that the reduction in the total time in port per year is at least reduced in such a way that the total time is equal to the number of operational days D before the speed reduction. In this case as we explained before there will be no need to add more ships to maintain the same yearly throughput.

In this case :

$$\left.\begin{array}{l} total\ time = constant \Rightarrow T_0^* + t_0^* = T^* + t^* = D \Rightarrow t^* = D - T^* \\ \dfrac{T^*}{T_0^*} = \dfrac{\frac{L^*}{24 \cdot V}}{\frac{L^*}{24 \cdot V_0}} \Rightarrow T^* = T_0^* \cdot \dfrac{V_0}{V} = T_0^* \cdot \dfrac{V_0}{aV_0} = \dfrac{T_0^*}{a} \end{array}\right\} t^* = D - \frac{T_0^*}{a} \quad (5)$$

3. EFFECT OF SPEED REDUCTION ON CONTAINER VESSELS

Lately, much attention has been given to speed reduction as this is the easiest emissions reduction measure that can be implemented. The question is whether this is cost-effective or not. When talking about a single roundtrip, a delay in arrival will distort the current status-quo. In the case of containers and passenger vessels this may lead to a modal shift and for sure will put the company out of competition. Furthermore, to maintain constant annual throughput, in most of the cases, more ships will have to be used.

Psaraftis and Kontovas (2009c) investigated the scenario where a fleet of N identical ships (N: integer), each of capacity (payload) W loads from a port A (time in port $T_{A,}$, days), travels to port B with known speed V_1, discharges at B (time in port T_B, days) and goes back to port A in ballast, with speed V_2. The main result of the analysis is that total emissions would be always reduced by slowing down, even though more ships would be used.

The present paper focuses on the case where total trip time is kept constant. Given the fact that time at sea increases with slow steaming we must investigate possible ways to decrease time in port. This is not an easy task. The most feasible way to reduce time in port is through operational decisions regarding quayside operations (berth allocation, quay cranes scheduling and vessel stowage). Optimizing terminal operations has received increasing interest over the last years. Vis and de Koster (2003) review the relevant literature and illustrate the main logistics processes in a container terminal whereas Steenken et al.(2004) provide an overview of optimization methods terminal operations. The problem of allocating ships to berths (discrete case) or to quays (continuous case) is dealt among others in Cordeau et al. (2005) and Wang and Lim (2007). The Quay Crane Scheduling Problem (QCSP) which refers to the allocation of cranes and to the scheduling of stevedoring operations can be solved with the use of dynamic programming as proposed in Lim et al (2004) or be addressed with a greedy randomized adaptive search procedure like the one analyzed in Kim and Park (2004). Lee et al. (2006) address a yard storage allocation problem to reduce traffic congestion and Lee and Hsu (2007) present model for container re-marshalling. For a circumstantial review of the operational research literature of problems related to container terminal management the reader could refer among others to Vis and de Koster (2003) and Steenken et al. (2004).
Given the fact that the current literature on the above matters is huge, there is enough evidence that time reduction in port is feasible.

We now move forward to a realistic example using the following figures that are based on operational data provided by Det Norske Veritas (DNV).

A Panamax container-vessel (name withheld) begins her trip from Port A, and then consequently visits ports B and C before going back. The time that she spends at sea and in port and the relating fuel consumptions are as follows :

Depart Port	Arrive Port	Distance (miles)	Avg speed (kn)	Total TEU	Sailing time (hrs)	F_0 (tn/day)	T_0 (days)	f (tn/day)	t_0 (days)
A	B	115	20.18	1892	5.70	91.79	0.24	16.58	1.79
B	C	6068	23.41	2593	259.20	136.81	10.80	3.26	5.45
C	A	6323	22.85	3294	276.70	139.22	11.53	12.15	3.55

Using Eq. 1a, 2a, 3a and we can calculate the reductions in fuel cost and emissions for each leg. For reasons of simplicity we omit the detailed calculations and we present the resulting total reductions for this round trip in Fig.3.

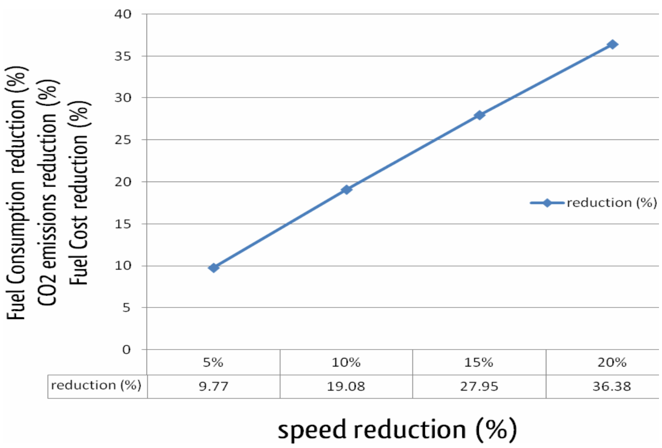


Fig. 3. Reductions in fuel consumption, CO2 emissions and Fuel Costs

One can observe some significant savings in fuel consumption, CO2 emissions (in fact, all emissions) and fuel cost. However, “there is no free lunch” necessarily. Compensating for a reduced speed will entail either additional ships to maintain the same throughput, or the ability to reduce port time. If the former can be achieved, overall emissions are shown to be reduced, but the overall cost (including cargo in-transit inventory cost) may or may not go down (Psaraftis and Kontovas, 2009c). Emissions can be reduced even further if port time can be reduced so that there is no need for additional vessels. But this may be a more difficult proposition. For instance, in the example illustrated above, when speed is reduced by 5 % , time in port has to be reduced by 11% to maintain a constant total trip time. If this sounds feasible, it is non-trivial nonetheless. For a speed reduction of 15% the total time in port has to be reduced from 10.8 days down to 6.81, which is almost a 37 % reduction. This is a much more difficult proposition, possibly entailing drastic port re-engineering and/or infrastructure improvements.

5. EFFECT OF SPEED REDUCTION ON FERRIES

In the case of ferries, especially those engaged in short sea shipping, reducing port time comes at no extra cost, as one can just reduce the time that ship stays idle in port. We can easily implement this under the assumption that the speed reduction will only lead to a small increase in total time so that passengers will still prefer using a ferry. Furthermore, this is feasible since ferries engaged in domestic sails and short sea shipping tend to spend a lot of time idle waiting for the next scheduled trip.

The figures below are based on operational data provided by a ferry company in Greece (which cannot be named) and were collected by the Hellenic Chamber of Shipping (HCS) (see Kontovas and Psaraftis (2008 and 2009a)).

A RoPax ferry is engaged in a roundtrip between ports A and B. The ship loads at A, sails to B where she unloads all cargo, stays idle for a couple of hours and then loads again and returns to port A. This is done repeatedly for a year. The following table includes all the parameters needed (i.e. fuel consumptions in tonnes per days and total time at sea and in port).

Time at sea (hours per year)	5600
Time in port (hours per year)	3160
Operating Days (D)	365
L (nm) per trip	95
Consumption at sea (tn/day)	63.6
Consumption in port (tn/day)	4.8
Speed (kn)	23.5

By using Eq. 1b,2b,3b and 5 the reduction in fuel consumption, CO_2 emissions and fuel costs on a per year basis can be calculated. Emissions and fuel costs are multiples of fuel consumption which means that the percentage of reduction for all three quantities is the same and can be seen in the following graph.

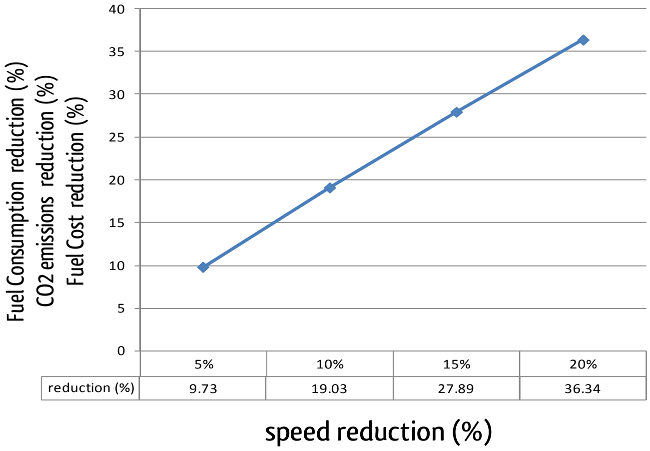


Fig. 4. Reductions in fuel consumption, CO2 emissions and Fuel Costs

We now make a cursory investigation of the case in which a ship (suppose the one used in this example) is involved in a regular route between EU ports and is forced to use low-sulphur fuel, to reduce SO_x emissions. This fuel is 4-30% more expensive than high-sulphur fuel (see Fig. 1). Hence freight rates may go up. Furthermore, according to a document submitted by INTERFERRY to MEPC 58 (IMO, 2008c) the rise in fuel prices over the past years and the cost increase for low sulphur fuel may force some operators out of the market. This may induce shippers to use land transport alternatives (trucking), which will go against stated policies toward shifting cargo from land to sea and increase CO_2 emissions through the logistics chain. The European Community Shipowners' Association (ECSA) has already warned that new sulphur limits agreed at the IMO could push more freight onto the roads in Europe (Lloyds List, 2008a). It is out of the scope of this paper but it is very interesting to investigate if freight rates did actually went up since the enforcement of EU directive 2005/33/EC and what was the effect of this on modal split.

For all the reasons above, it seems quite interesting to investigate the fuel cost saving due to speed reduction. In the above example, the fuel bill per year is about 10 million USD (when fuel prices are high, at about 650 $ per tonne) and about 4 million USD when fuel price is at its low. Fig.5 shows fuel cost reduction in USD per year given hypothetical speed reductions in the range of 5-20 % in two cases, one when fuel prices are high (p=650$) and another for low price (p=$250).

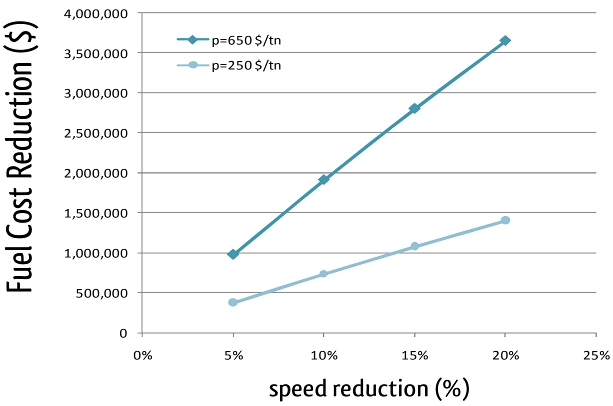


Fig. 5. Fuel Costs Reduction in USD per year

To summarize, there is enough evidence to suggest that shipping companies should be reducing sailing speed, especially in those cases that the increase of time at sea is a small fraction of total sea time. In the case above, a one knot speed reduction (approximately 5%) will lead to a 25 minute increase in voyage time (when the original time from port A to port be was at about 4hrs) and this would correspond to a 10% reduction in emissions and fuel costs.

4. CONCLUSION

Some speed reduction models and scenarios were presented and their effects on reducing emissions of fast ships were investigated. It was seen that speed reduction is beneficial in terms of reducing emissions, but the real effectiveness of such a scheme depends on the possibility of reducing port time as well. This means that the role of ports within the intermodal supply chain is of paramount importance, not only vis-à-vis the traditional logistics criteria, but also for overall ship emissions.

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