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REDUCTION OF GHG EMISSIONS FROM SHIPS

Technology take-up and its interaction with operational energy efficiency

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SUMMARY

Executive summary:	Both technology and operational interventions have consequences for a ship's commercial operation. It is proposed that existing attempts to model technology take-up and operational choices in a future fleet do not adequately represent the technical and economic interactions. This document presents a new model that can simulate these interactions, and discusses some results for a hypothetical ship (based on a VLCC). The results imply that operation to maximize a shipowner's profits could negate emissions reductions benefits achieved through technology investment.
Strategic direction:	7.3
High-level action:	7.3.2
Planned output:	7.3.2.1
Action to be taken:	Paragraph 23
Related documents:	Resolution A.963(23); MEPC 63/INF.7, MEPC 63/5/2; MEPC 64/5, MEPC 64/5/7; MEPC 59/INF.10; MEPC 61/INF.2, MEPC 61/INF.18 and MEPC 64/INF.14

Introduction

1 Assembly resolution A.963(23) urges the Committee to identify and develop the mechanisms needed to achieve limitation or reduction of GHG emissions from ships and to give priority to the evaluation of technical, operational and Market-based Measures (MBM). Document MEPC 63/5/2 calls for further work on MBM towards MEPC 65. Furthermore, document MEPC 64/5 proposes further impact assessment, including establishment of the environmental effectiveness (annex, paragraph 16.1) and cost-effectiveness (annex, paragraph 16.2).

2 The energy efficiency and carbon emissions of a ship are a function of both its technical specification and the way it is operated. Commonly an attempt to distinguish between the two has been used in order to add clarity, e.g. the existence of both the EEDI and EEOI, and as in document MEPC 64/5/7 submitted by the United States, the use of "technical efficiency" and "overall efficiency". Whilst it is hoped that improvements to a ship's technical efficiency will result in cost-effective environmental effectiveness, it is ultimately only the overall effectiveness that is significant in this respect.

3 The assessment of potential environmental and cost-effectiveness requires the description of a scenario that has not yet occurred, e.g. what happens if a new regulation is introduced, what happens if a new technology is developed. This can be done either through experimentation or modelling and simulation. For analysing the consequences of the adoption of a new regulation on the future GHG emissions of the shipping industry, experimentation is incompatible with the urgency expressed in A.963(23) and so, to date, models have been used. A common method is to estimate the take-up of technology using marginal abatement cost analysis to simulate the investment choices of firms in the shipping industry as a function of fuel and carbon price (MEPC 61/INF.2 and MEPC 61/INF.18). Such modelling approaches typically focus on changes to the technical efficiency, but have also been used to consider operational efficiency interventions. The Second IMO GHG Study (MEPC 59/INF.10) also quantified the carbon intensity reduction potential of technology and operations using marginal abatement cost curves (MACC). In appendix 2 of the annex to document MEPC 59/INF.10, it is noted that "Reductions in speed are expensive, since they directly affect the freight done and hence income of the ship". It is not clear in the Second IMO GHG Study what assumptions have been made in order to quantify this expense for the production of the MACC. However, the study's authors do clarify that "…the curve adopts a social perspective…it does not represent the expenditures that ship operators would have to make to do this" (paragraph 5.81, MEPC 59/INF.10). This implies that the method is not adequate for simulating the way that the industry is likely to respond to future fuel or carbon prices. No comment is made about the interaction between technology and operation, e.g. the incentivization or disincentivization of operational efficiency as a result of deployment of technical energy efficiency. Similarly, MEPC 61/INF.18 (annex, paragraph 1.8) pays attention to speed's potential for emission reduction "…speed reduction accounts for most of the estimated operational CO_2 emissions reductions…". However, their method is based on the theory of cost minimization. For speed, this includes the costs of additional tonnage required to maintain the transport supply. This approach would omit both the revenue impacts and the behaviour of firms that make decisions on the basis of profit maximization. No statement is made on the interaction between energy efficiency technology and operational efficiency.

4 In general, models can produce inaccurate or unreliable predictions because of: incorrect input data and assumptions, or a modelling method that is misrepresentative of the system it is simulating (e.g. in this case, shipping). Given the importance of GHG emission reduction from shipping, the cost and expense associated with the incorrect identification of environmental impact or cost-effectiveness, and the criteria required in the Impact Assessment proposal, it is suggested that it is important to ensure the highest quality (most rigorous and robust) modelling is used to inform the discussions at MEPC.

5 Notwithstanding the importance of the quality of input data, this document focuses on modelling methods and presents an alternative modelling framework to that used in previous simulations of future shipping emissions. The model evaluates the profit generated by a number of combinations of technical and operational parameters and identifies their selection for an individual shipping firm associated with maximized profits. A hypothetical example is used to illustrate the behaviour that this model predicts and discuss the

consequences for the MBM debate. A detailed description of the model can be found at (*http://www.future-science.com/doi/pdf/10.4155/cmt.12.58*).

6 The results suggest that operation to maximize a shipowner's profits can negate the benefit in emissions reductions achieved through technology. If the mitigation actions of technology are both to be optimized and protected from potential operational unintended consequences, it is important to understand these interactions and take them into account in the design of GHG-related policy.

Technology, operation and profit

7 Ship speed is central to the debate around shipping's GHG emissions, but as both a design and operation parameter it is complicated to model and analyse. It influences operating costs (fuel costs) and revenue (quality of service and quantity of voyages within a given time frame), is of high sensitivity to the overall efficiency and emissions of a ship, and is subject to various contractual constraints (all extensively discussed in MEPC 64/INF.14). Whilst in the past it has been included in marginal abatement cost analysis, this modelling method has constraints on the extent that both revenue and cost implications of the parameter can be considered along with the interaction between speed and technical interventions that could be considered for a design. It is proposed in this document that its consideration in impact assessments to date has been oversimplified.

8 In other examples of existing literature, ship speed has been considered as a stand-alone design parameter and an optimum derived using profit maximization, e.g. Ronen, "the effect of oil price on the optimal speed of ships". A summary of the form derived by Ronen and a discussion of some of the existing literature on ship speed can be found in Smith T.W.P et al. "On the speed of ships" (2011).

9 The proposed new framework for modelling technology and operation choices is derived according to the same profit maximization criteria used by Ronen. The annual profit π_{pa} that an owner-operated ship will make its owner can be expressed as:

$$\pi_{pa} = R_{pa} - C_{s\_pa} - C_{v\_pa}$$

Where C_{s_pa} is the annualized sunk (or fixed costs), made up of capital costs and operating costs, e.g. insurance, crew, maintenance, C_{v_pa} is the annual variable costs normally dominated by fuel consumption. R_{pa} is some expected annual revenue generated from a series of cargo movements. In the case of an owner-operated ship, a rational owner will select a design and operation specification that maximizes profit. In other cases (e.g. a voyage or time-chartered ship), there can be some modification to these terms and their components.

Estimating annual revenue and costs and their variation with technology and operation

10 Providing the demand exists, an increase in a ship's operating speed increases its productivity (output within a prescribed timescale) and therefore its revenue. Assuming constant speed of operation, the annualized revenue can be represented as a function of a ship's operating speed according to:

$$R_{pa} = p24.dwt.D_s.\eta_l.V$$

where p is the price paid ($) for units of transport supply (moving 1 tonne of cargo a distance of 1 nm, nautical mile), *dwt* is the cargo mass capacity (or deadweight) in tonnes, D_s is the number of days at sea per year, η_l is the loaded efficiency of the ship and V is its speed in nm per hour (knots).

11 The fixed costs of a ship will vary depending on its specification, which includes the engine (C_e), the basic hull costs (C_{h0}), and the costs of any energy efficiency technologies (e.g. C_{hE}). Higher performance specifications will, *ceteris paribus*, have higher fixed costs. The annualized sunk costs can be found by amortizing the fixed costs using some assumptions about the credit terms on which these costs are financed (interest rate d and mortgage pay-off period T) and adding this to the annualized operating cost (C_{o_pa}). This annualized operating cost could increase due to higher maintenance costs for ships operated at low load, but this increase is assumed to be negligible in relative terms.

$$C_{s\_pa} = \frac{\frac{\left(C_{h0} + C_{hE} + C_e\right)d}{1200}}{12\left(1 - (1 + \frac{d}{1200})\right)^{-12T}} + C_{o\_pa}$$

12 The annualized voyage costs are dominated by fuel costs. Higher operating speeds will increase the annual fuel costs and, relative to some baseline specification, investment in energy efficiency technology will reduce the fuel costs. A model to represent the relationships and their effects on voyage costs is given as:

$$C_{v\_pa} = D_s p_f \frac{24.P_{me0}.\left(\frac{100 - E}{100}\right).\left(\frac{V}{V_0}\right)^3 .sfc.L}{\eta_p}$$

where p_f the price of fuel per tonne, *sfc* is the specific fuel consumption, L is the intended operating loading of the engine (indicated as a percentage of the maximum power output), η_p is an efficiency coefficient to represent the losses due to operation of the ship in realistic conditions, P_{me0} is the installed power in a baseline ship, E is a percentage representing the energy saving of an energy efficiency technology intervention, V is a new speed and V_0 is the design speed of a baseline ship.

13 A more thorough derivation of these equations and discussion of the assumptions can be found at (*http://www.future-science.com/doi/pdf/10.4155/cmt.12.58).*

Worked example for a hypothetical ship, input assumptions

14 To illustrate what this model can tell us about the profit-maximizing choices for a newbuild ship, input assumptions are required. The input assumptions will vary significantly, depending on the detail of a ship's type and size. For this document, only input assumptions indicative of a very large crude carrier (VLCC) are used. The values chosen are based on the characteristics of the average ship in the largest tanker size category studied in the Second IMO Study (tankers above 200,000 dwt) and are listed in *http://www.future-science.com/doi/pdf/10.4155/cmt.12.58*. The specific results will therefore not be representative of other ship types and sizes, although the trends and sensitivities may be. Rather than using the models to quantify an exact solution, the aim in this submission is to communicate how technical and operational efficiency interacts. Consequently, the model's results are shown for ranges for some of the key independent variables. Those varied are technology cost, fuel price and shipping prices (freight rates).

15 There is an ongoing discussion about realistic performance and cost data for different technologies (MEPC 63/INF.7). To avoid clouding the results with these uncertainties, a broadly fictitious set of costs and efficiencies is used here, based loosely on the capital costs of existing improvement technologies discussed in the existing literature, such as rudder and propeller improvements, hull-form optimization and resistance-reduction technologies (air lubrication). The different levels of energy efficiency may be achieved by any 'package' of the various technologies:

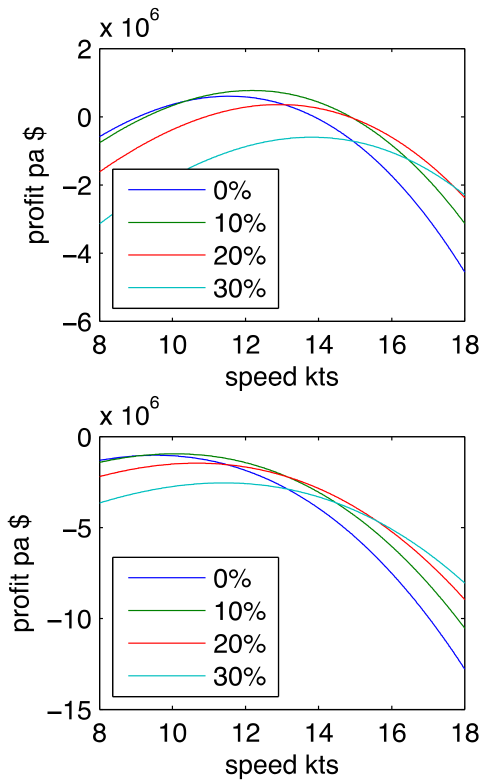
Propulsion energy saving	C_{hE_high}
0%	0
10%	$5m
20%	$20m
30%	$45m

16 Both the freight rate and fuel price are key determinants of the variation in revenue and costs. They are also variables for which there is future uncertainty. Four macro-economic scenarios are considered here to represent the various foreseeable combinations of high and low prices.

1. Low fuel price (400$/t), low freight rate (0.0012$/tnm)	2. Low fuel price (400$/t), high freight rate (0.0018$/tnm)
3. High fuel price (700$/t), low freight rate (0.0012$/tnm)	4. High fuel price (700$/t), high freight rate (0.0018$/tnm)

Worked example for a hypothetical VLCC, results

17 The consequence of adding energy efficiency technology into the profit maximization associated with speed can be seen in the figure below. The consequence of investing in energy efficiency technology is that the fuel consumption (at any given speed) reduces and the fixed costs increase. This means that the profit incentive to increase speed increases (the maximum of each curve in each macro-economic scenario moves to the right as a greater level of energy efficiency investment is made).



18 The overall optimum of speed and technology is identified by the maximum profit across all four curves. In some instances (scenarios 1, 3 and 4), the optimum investment is in 10 per cent energy savings; in one instance (scenario 2), it is for investment in 20 per cent energy savings. However, of key interest is the extent to which each combination of technology and speed changes the specific emissions. The table below shows the comparison of specific emissions between an example where no technology uptake occurs (Frozen) and the technology cost scenario examined here (High). In each specific macro-economic scenario, the specific emissions match regardless of technology uptake. The reason for this is that the greater technical efficiency achieved coincides with a higher optimum speed which has caused the technical efficiency gain to be negated by losses in operational efficiency.

Technology case	Macro-economic scenario	Optimum speed, kts	Specific emissions, gCO_2/tonnenm	Optimum technology saving
Frozen	1	11.6	2.9	0
	2	14.2	4.4	0
	3	9.5	2.0	0
	4	11.7	3.0	0
High	1	12.2	2.9	10%
	2	15.8	4.4	20%
	3	10.1	2.0	10%
	4	12.3	3.0	10%

Discussion of results

19 What is most significant from the results is the relationship between investment in energy efficiency technology and speed. Regardless of fuel price and freight rate, the greater the energy efficiency of the hull, the higher the speed at which profits are maximized.

The consequence of this is that for this example, there is no sensitivity to specific emissions as a function of the technology scenario (frozen or high cost).

20 It is emphasized that the results shown here are intended to be indicative of a trend; the specific commercial arrangements for the ownership and charter of a ship might create significant differences in practice from the identified optima.

21 The graphs show that the main determinant of the specific emissions (assuming the industry acts to profit-maximize) is the macro-economic scenario. For this particular example, the range of specific emissions is from 2-4.4 (even for the frozen technology baseline), which adds a large uncertainty to future shipping emissions estimates for which the input macro-economic backdrop is unknown.

22 The fact that the four scenarios show significant variation in the specific emissions shows the industry has good potential for GHG mitigation using MBMs. Carbon taxation is often considered equivalent to a surcharge on the fuel cost, and for the same freight rate, higher fuel prices result in lower specific emissions. However, the results show that it is not fuel price alone which determines specific emissions, but its combined consideration with freight rates. In the event that fuel price rises (or carbon taxation) is passed on to the customer through higher freight rates, it cannot be guaranteed that the consequence will be an emission reduction.

Action requested of the Committee

23 The Committee is invited to note the comments provided above and to take them into consideration when developing future measures to address the operational emissions of greenhouse gases from ships.

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