Speed Optimization vs Speed Reduction in Maritime Transport: the Speed Limit Debate

Harilaos N. Psaraftis
Professor, DTU
Main reference

- Paper submitted to *IAME 2019* (Athens)
- Paper submitted to *Sustainability* journal
A synthesis of work on

- Speed optimization in maritime transport
- The quest to reduce greenhouse gas (GHG) emissions from ships
Two tracks

The "science" track

- O(20) papers and book chapters on ship speed optimization
Two tracks

The “science” track

• O(20) papers and book chapters on ship speed optimization

The “policy” track

• Process at the International Maritime Organization (IMO) on GHG emissions reduction

(Both circa 2010)
Air emissions

GHG emissions

• Mainly CO2
• CH4
• N2O
• Etc

• 796 million tonnes of CO2 in 2012
• 2.2%

Non-GHG emissions

• SOx
• NOx
• P.M.
• etc
The "policy" track

Big news from the IMO: April 2018!

UN body adopts climate change strategy for shipping
“Initial IMO strategy”

CENTRAL AMBITION

• Reduce annual GHG emissions by ≥ 50% by 2050 (vs 2008 levels)

• Reduce annual CO2 emissions per transport work by ≥ 40% by 2030, pursuing efforts towards 70% by 2050 (vs 2008 levels)

• Q: How?
LONG LIST OF CANDIDATE MEASURES

HIERARCHY

• SHORT TERM (2018-2023)

• MEDIUM TERM (2023-2030)

• LONG TERM (2030 on)

EXAMPLES

• Speed reduction

• Market based measures

• Low carbon fuels
Among the short term measures

• “Speed reduction” was proposed as a key measure

• Advocates said it can have an immediate impact in reducing CO2

• Can be used as a bridge until more permanent measures are in place (eg, low carbon fuels)
2007 data: The top tier of the container fleet emits more CO2 than the entire tanker fleet.

Speed reduction (rationale)

- Pay less for fuel
- Reduce emissions
- Help sustain a volatile market

- Win-win-win?
- (killing 3 birds with one stone?)
Who opposed the Initial IMO Strategy?
Who opposed the Initial IMO Strategy?

- Brazil
- Saudi Arabia
- USA
Also

• Chile and Peru objected to "speed reduction" as a measure.
• Argued that sending cherries to China would suffer.
• Suggested using "speed optimization" instead
Compromise solution:

Include both!

• But, no one is really sure what is meant by “speed optimization”!

...consider and analyse the use of speed optimization and speed reduction as a measure, taking into account safety issues, distance travelled, distortion of the market or trade and that such measure does not impact on shipping's capability to serve remote geographic areas;
Speed tradeoffs

• A higher speed will be more costly in terms of fuel consumption

• FC vs speed: highly nonlinear

• BUT: A higher speed will earn more money per unit time (haul more cargoes)

• Hence, it makes sense to optimize it!
Speed reduction (rationale)

- Pay less for fuel
- Reduce emissions
- Help sustain a volatile market

- Win-win-win?
- (killing 3 birds with one stone?)
Win-win(-win)?

Side effects?
Win-win(-win)?

Side effects?

• You will need more ships to maintain throughput
• Or bigger ships
• These will come at a cost
Build more ships to match demand throughput

- More emissions due to shipbuilding and scrapping (life cycle analysis)
More ships also means

- More maritime traffic
- Implications on safety!
Yet another side-effect

• Cargo may shift to land-based modes, if these are available
  • This may result in more CO2

• European short-sea shipping
• Even in deep-sea shipping
Reduce speed: dual level targeting

- TACTICAL/OPERATIONAL
  - Operate existing ships at a reduced speed (slow steaming)

- STRATEGIC (DESIGN)
  - Design new ships that cannot go very fast (have smaller engines)
EEE is green

- Design speed: 17.8 knots
In many maritime OR/MS models

- Ship speed is assumed FIXED (NOT a decision variable)

- This may remove flexibility in the decision process and produce sub-optimal solutions
EXAMPLE 1

• Several models include
  – port capacity constraints,
  – berth occupancy constraints,
  – time window constraints,
  – or other constraints that preclude the simultaneous service of more than a given number of vessels.

• Such constraints might be easier to meet if ship speed was allowed to vary.
EXAMPLE 2

Handled a paper in *Tr. Sci.*

Topic: Schedule disruption in liner shipping

Key assumption: speed is **fixed**
EXAMPLE 2

Handled a paper in *Tr. Sci.*

Topic: Schedule disruption in liner shipping

Key assumption: speed is **fixed**

Outcome:

REJECTED
Speed basics

• Ships do NOT trade at predetermined speeds!
• **Those who pay for the fuel**, that is, the ship owner if the ship is in the spot market on voyage charter, or the charterer if the ship is on time or bareboat charter, will *choose an optimal speed* as a function of basically

  – (a) the fuel price, and
  – (b) the freight rate

• Higher fuel prices and/or lower freight rates will induce lower speeds (and vice versa)
Figure 2: VLCC Spot rate versus BFO price

Equiv TC rate, VLCC, P. G-East, kilo-day

BFO mt, Fujairah

2007  2008  2009  2010
Fuel consumption function

• $FC = kV^3$ (tons per day)
• Reasonable approximation in many cases
More general FC

• FC = (A+Bv^n)\Delta^{2/3}

\Delta = \text{ship’s displacement}

n \geq 3

Even more general
• FC = f(v, w) \text{ (general)}

• Depends on speed v and payload w
Speed taxonomy paper

Transportation Research Part C 26 (2013) 331–351

Contents lists available at SciVerse ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Overview Paper

Speed models for energy-efficient maritime transportation: A taxonomy and survey

Harilaos N. Psaraftis*, Christos A. Kontovas

Laboratory for Maritime Transport, National Technical University of Athens, Athens, Greece
Speed taxonomy paper

Purpose

• What has been done in this area?

• 42 papers reviewed

1st cut

• Non-emissions related (circa 1981)

• Emissions-related (circa 2009)
<table>
<thead>
<tr>
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<tbody>
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<td>Owner or charterer</td>
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<td>Fixed route</td>
<td>Berth allocation</td>
<td>Fixed route</td>
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<td>Pickup and delivery</td>
<td>Multiple ships</td>
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<td>Multiple ships</td>
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<td>Add more ships an option</td>
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</tbody>
</table>
How many speed papers?

• 42 surveyed in the 2013 paper

• How many since then?

• A good proxy is the # of citations of the 2013 paper
Citations of the 2013 paper:

222
Citations of the 2013 paper:

222

Most interesting citation

Meat Science
Volume 98, Issue 1, September 2014, Pages 71–80

Factors affecting microbial spoilage and shelf-life of chilled vacuum-d lamb transported to distant markets: A review

ša, Andrea Donnisona, Gale Brightwellb
Ship speed and Siberia

Balancing the economic and environmental performance of maritime transportation

Harilaos N. Psaraftis *, Christos A. Kontovas
Laboratory for Maritime Transport, National Technical University of Athens, Greece

• Use logit models to estimate modal shifts
Modeling Tankers’ Optimal Speed and Emissions

Konstantinos G. Gkonis (V) and Harilaos N. Psaraftis (FL)
Laboratory for Maritime Transport
School of Naval Architecture and Marine Engineering
National Technical University of Athens

• One ship model

• Fleet model
Combining speed and routing decisions
Speed and ECAs (emission control areas)

Kjetil Fagerholt, Nora T. Gausel, Jørgen G. Rakke, Harilaos N. Psaraftis

Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology, Trondheim, Norway

Norwegian Marine Technology Research Institute (MARINTEK), Trondheim, Norway

Department of Transport, Technical University of Denmark, Lyngby, Denmark
Speed and ECAs ii

On two speed optimization problems for ships that sail in and out of emission control areas

Kjetil Fagerholt\textsuperscript{a,b}, Harilaos N. Psaraftis\textsuperscript{c,*}

\textsuperscript{a} Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology, Trondheim, Norway
\textsuperscript{b} Norwegian Marine Technology Research Institute (MARINTEK), Trondheim, Norway
\textsuperscript{c} Department of Transport, Technical University of Denmark, Lyngby, Denmark
Dynamic speed

The economic speed of an oceangoing vessel in a dynamic setting

Evangelos F. Magirou\textsuperscript{a,}\textsuperscript{*}, Harilaos N. Psaraftis\textsuperscript{b}, Theodore Bouritas\textsuperscript{a}

\textsuperscript{a}Athens University of Economics and Business, Department of Informatics, Patission 76, Athens 10434, Greece
\textsuperscript{b}Technical University of Denmark, Department of Transport, Bygningsstorvet 1, 2800 Kgs. Lyngby, Denmark
Speed with flexible frequencies

The profit maximizing liner shipping problem with flexible frequencies: logistical and environmental considerations

Massimo Giovannini¹ · Harilaos N. Psaraftis²
A tactical level **fixed route** problem

- Assumes a fleet of $N$ identical containerships deployed on a given **fixed route**
  - Can be generalized to non-identical ships

- **WHAT IS OPTIMIZED?**
  - Maximize the **average per day profit** of the carrier.

- Any route topology can be examined
Mathematical formulation

\[
\hat{\pi} = \max_{v_i, t_0, N} \left\{ \frac{1}{t_0} \left( \sum_x \sum_z F_{xz} c_{xz} - P \sum_i f(v_i) \frac{L_i}{24 v_i} - PA \sum_j G_j - \sum_i \alpha_i C_i \frac{L_i}{24 v_i} - H \sum_j D_j \right) - NE \right\}
\]

subject to the following constraints:

\[
v_{\text{min}} \leq v_i \leq v_{\text{max}} \quad i \in I
\]

\[
N t_0 = \sum_i \frac{L_i}{24 v_i} + \sum_j G_j
\]

and

\[
N \in \mathbb{N}^+. \quad (12)
\]
Observation:

BOTH obj. fcn. and constraints are NONLINEAR

\[
\hat{\pi} = \text{Max}_{v_i, t_0, N} \left\{ \frac{1}{t_0} \left( \sum_x \sum_z F_{zx} c_{zx} - P \sum_i f(v_i) \frac{L_i}{24v_i} - PA \sum_j G_j - \sum_i \alpha_i C_i \frac{L_i}{24v_i} - H \sum_j D_j \right) - NE \right\}
\]

(9)

subject to the following constraints:

\[
v_{\text{min}} \leq v_i \leq v_{\text{max}} \quad i \in I
\]

(10)

\[
Nt_0 = \sum_i \frac{L_i}{24v_i} + \sum_j G_j
\]

(11)

and

\[
N \in \mathbb{N}^+.
\]

(12)
KEY FINDING

FREQUENCY OF ONE CALL PER WEEK NOT NECESSARILY OPTIMAL

Requiring frequency to be one call per week may restrict feasible solution space and will generally entail a cost.

Set of allowable service periods (days):

\[ S = \{3.5, 4, 5, 6, 7, 8, 9, 10, 14\} \]

- Twice a week
- Weekly
- Biweekly
Fig. 10  Number of ships bounded above scenario, optimal service period and optimal average speed at different bunker prices (route AE2)
Chile and Peru

- They objected to “speed reduction” as a measure.
- Argued that sending cherries to China would suffer.
- Suggested using “speed optimization” instead.
Service

Source: ShipCLEAN project (2018)
Vessels deployed in a TransPacific service

**EASTBOUND**: Xiamen, Ningbo, Shanghai, Manzanillo, Buenaventura, Callao, San Antonio

**WESTBOUND**: Callao, Manzanillo, Kaohsiung, Yantian, Hong Kong, Xiamen
Focus – Containership
EXPRESS BERLIN

Built in 2011
Design speed: 25.2 knots
Chartered for: YANG MING LINE (previously: HANJIN)

Main Engine Power 68600 kW
10100 TEU
1400 reefers
More Info on the Service

Average service speed: 15.9 knots
Corresponds to about 18.5% of MCR!

25% MCR: 17 knots
50% MCR: 22 knots
75% MCR: 25.2 knots
100% MCR: 27.7 knots

10% MCR: 12.6 knots

Maximum Continuous Rating (max engine power)
More Info on the Service

Average service speed: 15.9 knots
Corresponds to about 18.5% of MCR!

25% MCR: 17 knots
50% MCR: 22 knots
75% MCR: 25.2 knots
100% MCR: 27.7 knots

10% MCR: 12.6 knots

1st OBSERVATION: SLOW STEAMING BIG TIME!
2\textsuperscript{nd} observation: speed profile

Speed per leg (knots)

According to Published Schedule | Actual

Kaohsiung - Yantian, Yantian - Hong Kong, Hong Kong - Ningbo, Ningbo - Shanghai, Shanghai - Manzanillo, Manzanillo - Buenaventura, Buenaventura - Callao, Callao - San Antonio, San Antonio - Callao, Callao - Manzanillo, Manzanillo - Hong Kong
2nd observation: speed profile

![Graph showing speed per leg (knots) for different routes. The graph compares actual speeds with speeds according to the published schedule.](image)

- **EASTBOUND**
  - Kaohsiung - Yantian
  - Yantian - Hong Kong
  - Hong Kong - Ningbo
  - Ningbo - Shanghai
  - Shanghai - Manzanillo
  - Manzanillo - Buenaventura
  - Buenaventura - Callao
  - Callao - San Antonio
  - San Antonio - Callao
  - Callao - Manzanillo
  - Manzanillo - Hong Kong

- **WESTBOUND**

Legend:
- Blue: According to Published Schedule
- Gray: Actual
Speed imbalances

**EASTBOUND:** Xiamen, Ningbo, Shanghai, Manzanillo, Buenaventura, Callao, San Antonio

**WESTBOUND:** Callao, Manzanillo, Kaohsiung, Yantian, Hong Kong, Xiamen

Source: ShipCLEAN project (2018)
How can one explain speed imbalances?
How can one explain speed imbalances?

• (Commercial) factors:
  • Difference in values of cargo
  • Difference in load factors
  • More expensive cargoes sail faster
  • Fuller ships sail faster
Can be shown that

\[ v_1^3 - v_2^3 = k(P_1u_1 - P_2u_2)Q/p \]

- Ship capacity
- Fuel price
- Values of cargo
- Load factors
- Constant
The speed limiters lobby

- **Speed limits** have been proposed by some NGOs

- These NGOs have been lobbying the IMO and the EU for years
Tried before in 2010

MEPC 61

- CSC: “speed reduction should be pursued as a regulatory option in its own right and not only as possible consequences of market-based instruments or the EEDI.”

- RESULT:

[REJECTED stamp]
CE Delft study 2017

• Speed limits as functions of ship type and size
On the table as of 2018!

SET OF SHORT-TERM MEASURES (2018-2023)

consider and analyse the use of speed optimization and speed reduction as a measure, taking into account safety issues, distance travelled, distortion of the market or trade and that such measure does not impact on shipping's capability to serve remote geographic areas;
Central question

In IMO lingo

• Speed reduction, or speed optimization?

Substance-wise

• Reduce speed via speed limits, or via a bunker levy?

• Both measures would reduce speed, hence emissions
Important note!

A bunker levy is NOT explicitly included in the set of measures currently considered by the IMO

Only *obliquely* included under **medium term measures (2023-2030):**

3. **new/innovative emission reduction mechanism(s), possibly including Market-based Measures (MBMs),** to incentivize GHG emission reduction;
Question

• Which is better, a bunker levy or a speed limit?

• ANSWER:

• Depends. A speed limit can cause higher, lower, or the same CO2 reductions as a bunker levy.
Rudimentary scenario

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<th>Value</th>
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<tr>
<td>SHIP CAPACITY</td>
<td>10,000 TEU</td>
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<tr>
<td>ROUTE LENGTH</td>
<td>20,000 nm</td>
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<tr>
<td>FREIGHT RATE (base case)</td>
<td>1,500 USD/TEU</td>
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<tr>
<td>CAPACITY UTILIZATION</td>
<td>0.6</td>
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<tr>
<td>FUEL PRICE (base case)</td>
<td>500 USD/tonne</td>
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<td>MINIMUM SPEED</td>
<td>16 knots</td>
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<td>MAXIMUM SPEED</td>
<td>26 knots</td>
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<tr>
<td>OPEX</td>
<td>15,000 USD/day</td>
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</table>
Assume also

Fuel consumption cubic with speed
FC = 144 tonnes/day when v = 22 knots

Optimal speed is defined as the speed that maximizes the ship operator’s average per day profit
Result #1: A stronger market induces higher speeds and hence more CO2

Optimal speed  CO2

![Graphs showing the relationship between freight rate and optimal speed, and between freight rate and CO2 emissions.](image)
Result #2: a bunker levy reduces optimal speed
Result #3: CO2 can be reduced two ways

Bunker levy  

Speed limit

![Graph: Bunker Levy vs. CO2 Reduction](image1)

![Graph: Speed Limit vs. CO2 Reduction](image2)
Result #4: equivalence between levy and speed limit

• For any given levy, an equivalent speed limit can be found so that CO2 reduction is exactly the same

• However, other attributes of the solution will be different

• (but this will be ship specific, route specific and scenario specific!)
Main differences

A speed limit

• Will require no levy to be paid and hence the ship owner’s profit will be higher

• Will achieve no internalization of external costs of CO2

Also

• No application of the “polluter pays” principle

• No money collected
Main problems

• A **uniform** speed limit will not work
• Will apply to some ships, will be superfluous to some others, depending on ship type, size, trade, route direction, state of market, etc

• If speed limit is ship/route/direction/etc specific, implementing and enforcing it will be an administrative nightmare
Main problems ii

- Speed limit will provide no incentive to build & operate energy efficient ships
- Speed limit will penalize energy efficient ships, forcing them to sail at same speed as their energy inefficient competitors
# Comparison

<table>
<thead>
<tr>
<th>ISSUE</th>
<th>Speed limit</th>
<th>Speed optimization (with bunker levy)</th>
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<tbody>
<tr>
<td>Timing of measure within IMO Initial Strategy</td>
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<td>Medium-term</td>
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<td>Reduce GHG emissions</td>
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<td>Apply the polluters pay principle</td>
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<td>Internalize the external costs of GHG emissions</td>
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<td>Collect monies for out-of-sector emissions reductions, LDCs or SIDS</td>
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<td>Short term effect: freight rate increase</td>
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## Comparison ii

<table>
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<th>Speed optimization (with bunker levy)</th>
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</thead>
<tbody>
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<td>Long term effect: build more ships</td>
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<td>Yes (less pronounced)</td>
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<td>Market distortions</td>
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<td>Increase in lifecycle GHG emissions</td>
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<td>Burden to administer</td>
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<td>Incentive to economize and improve efficiency</td>
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<td>Compatible with virtual arrival</td>
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Main results (thus far)

• Speed reduction will indeed reduce GHG emissions
• Big confusion on how to achieve speed reduction
• True that the speed limit option may buy some time within the whole IMO debate on GHGs.
• May also give a signal that looks politically correct, that the IMO has moved boldly and took a first step towards GHG emissions reduction.
• However, it will also create many distortions and other problems and because of this the measure should be avoided.
The SOx connection

• Global 0.5% sulphur cap (1/1/2020)
• Fuel prices (MGO, MDO) are expected to rise
• A slow-down of the fleet is expected

• Except: ships with scrubbers will still be able to burn the (cheaper) HFO
• Hence these ships will sail faster!
• How much faster, no one knows.
The SOx connection ii

- Producing low S fuel emits CO2
- SOx trapping devices like scrubbers increase fuel consumption hence CO2
- More expensive low S fuel may cause modal shifts (mainly to road) hence more CO2
- SOx causes radiative cooling, hence reducing SOx may increase global warming!
### IMO: The way to 2023 (MEPC 80)

#### ANNEX

<table>
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<th>Streams of activity</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
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<tbody>
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<td>Candidate short-term measures (Group A) that can be considered and addressed</td>
<td>Invite concrete proposals</td>
<td>Consideration of proposals</td>
<td>Consideration and decisions on candidate short-term measures that can be considered and addressed under existing IMO instruments e.g. further improvement of the existing energy efficiency framework with a focus on EEDI and SEEMP, ITCP&lt;sup&gt;3&lt;/sup&gt;</td>
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<td>under existing IMO instruments&lt;sup&gt;2&lt;/sup&gt;</td>
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<td>Invite concrete proposals</td>
<td>Consideration of proposals</td>
<td>Consideration and decisions on candidate short-term measures that are not work in progress and are subject to data analysis, consistent with the Roadmap&lt;sup&gt;3&lt;/sup&gt;</td>
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<td>Data analysis, in particular from IMO Fuel Oil Consumption DCS</td>
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<td>Consideration of proposals</td>
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<td>Candidate mid-/long-term measures and action to address the identified barriers</td>
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<td>Consideration of proposals</td>
<td>Progress made and timelines agreed on the development of mid- and long-term measures</td>
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<td>Impacts on States&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Invite concrete proposals</td>
<td>Finalization of procedure</td>
<td>Measure-specific impact assessment, as appropriate, consistent with the Initial Strategy, in particular paragraphs 4.10 to 4.13</td>
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<td>Progress report</td>
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<td>Development and implementation of actions including support for assessment of impacts and support for implementation of measures</td>
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<td>Follow-up actions towards the development of the revised Strategy</td>
<td>Ship fuel oil consumption data collection pursuant to regulation 22A of MARPOL Annex VI (DCS)</td>
<td>Initiation of revision of the Initial Strategy taking into account IMO DCS data and other relevant information</td>
<td>Adoption of revised Strategy</td>
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<sup>2</sup> Includes ongoing work pursuant to regulation 21.6 of MARPOL Annex VI.

<sup>3</sup> *In aiming for early action, the timeline for short-term measures should prioritize potential early measures that the Organization could develop, while recognizing those already adopted, including MARPOL Annex VI requirements relevant for climate change, with a view to achieve further reduction of GHG emissions from international shipping before 2023* (paragraph 4.2 of the Initial Strategy).

<sup>4</sup> Assessment of impacts on States to be undertaken in accordance with the procedure to be developed by the Organization.
AFTER A FIERCE DEBATE: “prioritization” changed to “consideration”

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<tr>
<th>Streams of activity</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
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<tr>
<td>Candidate short-term measures (Group A) that can be considered and addressed under existing IMO instruments (^2)</td>
<td>Invite concrete proposals</td>
<td>Consideration of proposals</td>
<td>Consideration and decisions on candidate short-term measures that can be considered and addressed under existing IMO instruments e.g. further improvement of the existing energy efficiency framework with a focus on EEDI and SEEMP, ITCP (^3)</td>
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</table>
Q: Any measure that might work?

A: A significant bunker levy
   - SHORT RUN: reduce speed
   - LONG RUN: incentivize technologies or low carbon fuels that would reduce GHG emissions

(if fossil fuels are cheap, people will use them)
VLCC emissions

Gkonis and Psaraftis (2012)
In the long run

• Drastic GHG reductions can only come from low carbon fuels

• Need market based incentives to make these fuels economically viable
Way ahead

• Interesting to see how IMO will proceed
  – Next meeting: MEPC 74 (13-17 May 2019)

• (personal opinion) **BIG MESS if speed limits are adopted!**
Some selected papers


Fagerholt, K., Psaraftis, H.N., 2015, On two speed optimization problems for ships that sail in and out of emission control areas, Transportation Research Part D, 39, 56-64, 2015.


Most recently

Chapter 10
Speed Optimization for Sustainable Shipping

Harilaos N. Psaraftis
THANK YOU

hnpsar@dtu.dk
Appendix

INTERSESSIONAL MEETING OF THE
WORKING GROUP ON REDUCTION OF
GHG EMISSIONS FROM SHIPS
4th session
Agenda item 3

FURTHER CONSIDERATION OF HOW TO PROGRESS THE MATTER OF
REDUCTION OF GHG EMISSIONS FROM SHIPS

The optimization of routes as a short-term measure

Submitted by Panama