Greener approach to ship design and optimal route planning

Jasna Prpić-Oršić*, ***
Odd Magnus Faltinsen***

* Faculty of Engineering, University of Rijeka, Croatia
*** Centre for Autonomous Marine Operations and Systems (AMOS), Department of Marine Technology, NTNU, Trondheim, Norway

AMOS, NTNU, Trondheim, 4th March 2015

Supported by:

J. Prpić-Oršić, O. M. Faltinsen: Energy efficiency approach to ship design and route planning
Summary

Basic characteristics of an efficient transportation are safety, cost effectiveness and friendliness with the environment. According to various environmental impact assessments, ocean-going vessels, as the most important part of maritime transportation industry, will have increasing influence on the global ecosystem in the near future. In the modern approach to ship design the problems related to energy efficiency and environmental protection must not be left aside. A methodology for estimating the attainable speed in moderate and severe sea is proposed. Reliable ship speed loss estimation under real environmental conditions allows a more accurate prediction of the power increase and fuel consumption as well as gas emissions from ships.

The objective is to improve ship design and performance taking into accounts the environmental issue, creating a so-called eco-efficient or “green” ship design. The problem is multidisciplinary and requires the joint work of experts in the naval architecture, mechanical engineering, marine engineering and other engineering field.
Contents:

1. Introduction
2. Model of speed loss calculation
3. Numerical results
4. Conclusions
1. Introduction
1. Introduction

Assessment of potential reductions of CO$_2$ emissions from shipping by using known technology and practices (Marine Environment Protection Committee (MEPC) 59 Report, April, 2009)

**Design (new ships)**
- Concept, speed and capability (practical constrains): 2% to 50%
- Hull and superstructure: 2% to 20%
- Power and propulsion systems: 5% to 15%
- Low-carbon fuels: 5% to 15%
- Renewable energy: 1% to 10%

**Operation (all ships)**
- Fleet management & logistics: 5% to 50%
- Voyage optimization: 1% to 10%
- Energy management: 1% to 10%

Combined:
- Saving of CO$_2$, tonne-mile: 10% to 50%
- Combined: 25% to 75%
1. Introduction

Energy Efficiency Design Index (EEDI)

Energy Efficiency Operational Indicator (EEOI)

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
1. Introduction

Energy Efficiency Design Index (EEDI)

Measure: \( \frac{\text{Cost (i.e. emission)}}{\text{Transport work capacity}} \)

Unit: \( \frac{\text{g CO}_2}{\text{deadweight tonnage \cdot nautical mile}} \)

Average Emission (g CO2/ton-n.mile)

Cost (i.e. emission)

Average CO2 index and average gross tonnage for ship groups and individual observations.

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning.
1. Introduction

Reference line value EEDI

Attained $\leq$ Required EEDI

Phase 0 Required EEDI

Phase 1 Required EEDI

Phase 2 Required EEDI

Phase 3 Required EEDI

Fig. 2. Required EEDI

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
2. Speed loss calculation

ATTAINABLE SPEED CALCULATION
by using Newton’s law

- Time domain wave trace
- Ship motion and added resistance calculation
- Still water resistance calculation
- Wind resistance calculation
- Open water propeller characteristics
- Effect of ventilation
- Calculation of relative motion
- Diesel engine dynamics
- Speed trace
- Fuel consumption
- CO2 emission

Fig. 3. Scheme of the computations of ship speed in a given sea state

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
3. Numerical results

Fig. 5. Time trace of ship speed in head waves ($H_{1/3} = 6.00$ m)
3. Numerical results

Fig. 6. Voluntary speed reduction in head waves ($H_{1/3} = 6$ m)
3. Numerical results

Fig. 7. Average ship speed for involuntary and voluntary speed reduction in head and following waves

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
3. Numerical results

Fig. 8. Specific fuel consumption in head waves ($H_{1/3} = 4$ m)
3. Numerical results

Fig. 9. Specific fuel consumption in head waves ($H_{1/3} = 7$ m)
3. Numerical results

Fig. 10. Specific fuel consumption in head waves – voluntary speed reduction ($H_{1/3} = 4 \text{ m}$)

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
3. Numerical results

![Graph showing specific fuel consumption (SFOC) and wave height over time.]

**Fig. 11.** Specific fuel consumption in head waves – voluntary speed reduction ($H_{1/3} = 7$ m)

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
3. Numerical results

Fig. 12. Average specific fuel consumption for involuntary and voluntary speed reduction

Containership $L=175$ m
ITTC spectrum
Head and following sea

SFOC (g/kWh)

Significant wave height (m)

Involuntary speed reduction - Following sea
Voluntary speed reduction - Following sea
Involuntary speed reduction - Head sea
Voluntary speed reduction - Head sea
3. Numerical results

Fig. 13. Average CO$_2$ emission for involuntary and voluntary speed reduction in head waves

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
3. Numerical results

Fig. 14. Attainable ship speed for involuntary and voluntary speed reduction

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
3. Numerical results

Fig. 15. Fuel consumption for involuntary and voluntary speed reduction

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
3. Numerical results

Fig. 16. CO2 emissions for involuntary and voluntary speed reduction

J. Prpić-Oršić, O. M. Faltinsen: Greener approach to ship design and optimal route planning
3. Numerical results

Fig. 17. Speed reduction vs. initial speed for different loading conditions
3. Numerical results

Fig. 18. Speed reduction vs. draft (loading condition) for different speeds
3. Numerical results

Fig. 19. Main North Atlantic trans-oceanic routes
3. Numerical results

Hindcast data set was produced in the EU project HIPOCAS (Guedes Soares, 2008) and includes a 44 years database (January 1958 to December 2001) of wave, wind and sea level data for the Atlantic Ocean and all seas around Europe.

Fig. 20. Example of route panels
Table 2. Absolute fuel consumption during voyage (calm weather condition).

<table>
<thead>
<tr>
<th>Route</th>
<th>Route</th>
<th>Route</th>
<th>Route</th>
<th>Route</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Length [nmi]</td>
<td>3210</td>
<td>3253</td>
<td>2811</td>
<td>3048</td>
<td>2740</td>
</tr>
<tr>
<td>Time [h]</td>
<td>147.3</td>
<td>149.2</td>
<td>129.0</td>
<td>139.8</td>
<td>125.7</td>
</tr>
<tr>
<td>FOC [t]</td>
<td>654.73</td>
<td>663.54</td>
<td>573.34</td>
<td>621.69</td>
<td>558.91</td>
</tr>
<tr>
<td>CO₂ [kg]</td>
<td>2077.5</td>
<td>2105.4</td>
<td>1819.2</td>
<td>1972.6</td>
<td>1773.4</td>
</tr>
</tbody>
</table>

Table 3. Fuel consumption and CO₂ emissions (real weather conditions – involuntary speed reduction).

<table>
<thead>
<tr>
<th>Route</th>
<th>Route</th>
<th>Route</th>
<th>Route</th>
<th>Route</th>
<th>Route</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Speed [kn]</td>
<td>20.9</td>
<td>20.7</td>
<td>20.2</td>
<td>21.2</td>
<td>20.6</td>
<td>20.8</td>
</tr>
<tr>
<td>Time [h]</td>
<td>153.6</td>
<td>157.2</td>
<td>138.9</td>
<td>143.8</td>
<td>133.2</td>
<td>132.7</td>
</tr>
<tr>
<td>% increase</td>
<td>4.3%</td>
<td>5.3%</td>
<td>7.7%</td>
<td>2.9%</td>
<td>6.0%</td>
<td>4.7%</td>
</tr>
<tr>
<td>FOC [kg/km]</td>
<td>114.7</td>
<td>115.3</td>
<td>115.6</td>
<td>112.7</td>
<td>114.5</td>
<td>113.6</td>
</tr>
<tr>
<td>% increase</td>
<td>4.2%</td>
<td>4.6%</td>
<td>5.0%</td>
<td>2.3%</td>
<td>4.0%</td>
<td>3.1%</td>
</tr>
<tr>
<td>CO₂ [kg/km]</td>
<td>364.0</td>
<td>365.7</td>
<td>366.9</td>
<td>357.6</td>
<td>363.4</td>
<td>360.4</td>
</tr>
</tbody>
</table>
3. Numerical results

Fig. 21. Time increase and CO₂ emission increase (involuntary speed reduction)
Table 2. Absolute fuel consumption during voyage (calm weather condition).

<table>
<thead>
<tr>
<th></th>
<th>Route 1</th>
<th>Route 2</th>
<th>Route 3</th>
<th>Route 4</th>
<th>Route 5</th>
<th>Route 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length [nmi]</td>
<td>3210</td>
<td>3253</td>
<td>2811</td>
<td>3048</td>
<td>2740</td>
<td>2762</td>
</tr>
<tr>
<td>Time [h]</td>
<td>147.3</td>
<td>149.2</td>
<td>129.0</td>
<td>139.8</td>
<td>125.7</td>
<td>126.7</td>
</tr>
<tr>
<td>FOC [t]</td>
<td>654.73</td>
<td>663.54</td>
<td>573.34</td>
<td>621.69</td>
<td>558.91</td>
<td>563.32</td>
</tr>
<tr>
<td>CO₂ [kg]</td>
<td>2077.5</td>
<td>2105.4</td>
<td>1819.2</td>
<td>1972.6</td>
<td>1773.4</td>
<td>1787.4</td>
</tr>
</tbody>
</table>

Table 4. Fuel consumption and CO₂ emissions (real weather conditions – voluntary speed reduction).

<table>
<thead>
<tr>
<th></th>
<th>Route 1</th>
<th>Route 2</th>
<th>Route 3</th>
<th>Route 4</th>
<th>Route 5</th>
<th>Route 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed [kn]</td>
<td>20.3</td>
<td>19.9</td>
<td>19.3</td>
<td>20.8</td>
<td>19.8</td>
<td>20.2</td>
</tr>
<tr>
<td>Time [h]</td>
<td>158.4</td>
<td>163.1</td>
<td>145.8</td>
<td>146.7</td>
<td>138.4</td>
<td>136.8</td>
</tr>
<tr>
<td>% increase</td>
<td>7.6%</td>
<td>9.3%</td>
<td>13.1%</td>
<td>4.9%</td>
<td>10.1%</td>
<td>8.0%</td>
</tr>
<tr>
<td>FOC [kg/km]</td>
<td>103.2</td>
<td>102.2</td>
<td>99.5</td>
<td>104.6</td>
<td>100.8</td>
<td>102.2</td>
</tr>
<tr>
<td>% increase</td>
<td>-6.3%</td>
<td>-7.2%</td>
<td>-9.7%</td>
<td>-5.0%</td>
<td>-8.4%</td>
<td>-7.2%</td>
</tr>
<tr>
<td>CO₂ [kg/km]</td>
<td>327.5</td>
<td>324.4</td>
<td>315.6</td>
<td>332.0</td>
<td>320.0</td>
<td>324.1</td>
</tr>
</tbody>
</table>
3. Numerical results

Fig. 22. Time increase and CO$_2$ emission increase (voluntary speed reduction)
4. Conclusions

The proposed method allows reliable prediction of voyage duration and fuel consumption as well as CO$_2$ emissions from main engine. It allows considering various strategies and scenarios of voyage and selection of the optimal one taking into account ship safety and operability as well as economic and environmental aspects.

Knowing the mean values of speed loos, fuel consumption and CO$_2$ emission for the whole range of different ship loading cases and service speeds the ship owner would be able to estimate the economic benefit of various voyage regimes taking into account ship safety and, of course, the ship mission.

Further research

- Computationally faster engine model
- Relative importance of chosen voluntary speed reduction criteria
- Optimum hull design (minimized resistance)
- Uncertainties and reliability of the methodology
- Optimal vessel route planning ...
Thank you for your attention