A Study on Energy Efficiency Design Index for ro-ro pax ships

Spyros Zolotas
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- Sample selection criteria
- Sample analysis
- Data analysis
  - Reference lines using IMO Guidelines
  - Alternative definitions of “Capacity”
- Summary of attempts (all with very low R\(^2\))
- New approach:
  - Speed as parameter
  - PAE = 0.35*(total auxiliary power)
  - GT as capacity
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Sample selection criteria

- IHS Fairplay CD-ROM Version N.11, February 2011 (997 Ships)
- RO-RO passenger ships with conventional propulsion system
  - Date of build: 01 January 1999 – 01 January 2011
  - GT>400
  - Speed: 15-30 Kn

P_{AE} calculated as per cargo ships =

\[ P_{AE} = \begin{cases} 
0.025 \times \frac{\sum MCR_{ME}}{280} & \text{MCR}_{ME} > 10000 \text{ kW} \\
0.05 \times \sum MCR_{ME} & \text{MCR}_{ME} < 10000 \text{ kW}
\end{cases} \]

Data source: IHS Fairplay
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Qualitative and Quantitative Analysis of the Sample (Ro-Pax Ship’s Type)

<table>
<thead>
<tr>
<th>GT (tons)</th>
<th>V_{ref} (Kn)</th>
<th>P_{ME} (Kw)</th>
<th>L_{BP} (m)</th>
<th>B (m)</th>
<th>Draft (m)</th>
<th>Pax (N.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>441-75027</td>
<td>15 – 32</td>
<td>1394-67200</td>
<td>43 – 226</td>
<td>9.8-41.4</td>
<td>2.2-8.8</td>
</tr>
</tbody>
</table>

The situation is better understood simply having a look to the photos below:

From 450 GT to 75000 GT
Flag <<< GT Range

Flag <<< GT %
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  - $GT$ as capacity
Real Data of around 30 Ships checked against the IHS Fairplay GT and installed power
Real Data of around 30 Ships checked against the IHS Fairplay

LBP and speed
Real Data of around 30 Ships checked against the IHS Fairplay Breath and EEDI
Real Data of around 30 Ships checked against the IHS Fairplay Speed & Power
Simplified Uncertainty Analysis
(performed by using extension of the
ISO or ASME Standards or ITTC Procedures)

Only ships outside the Uncertainty Band can be considered as good or bad ships (with 95% of likelihood).

Nothing can be said for ships inside the Uncertainty Band.
<table>
<thead>
<tr>
<th>Attempts</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT as capacity, formula in accordance with MEPC.1/ Circ 681</td>
</tr>
<tr>
<td>Previous line without outliers</td>
</tr>
<tr>
<td>Ships characterized by GT&gt;3.000</td>
</tr>
<tr>
<td>Ships with only passengers onboard (no only truck drivers)</td>
</tr>
<tr>
<td>$1 &lt; \frac{P_{ME}}{P_{ADM}} &lt; 2$</td>
</tr>
<tr>
<td>Upper sample (empirical separation law)</td>
</tr>
<tr>
<td>Lower sample (empirical separation law)</td>
</tr>
<tr>
<td>Daily service</td>
</tr>
<tr>
<td>Overnight service</td>
</tr>
<tr>
<td>DWT as capacity</td>
</tr>
<tr>
<td>GT eq as capacity (function of cars, trucks and passengers number)</td>
</tr>
<tr>
<td>Optimal Baselines for Optimal Ships</td>
</tr>
</tbody>
</table>

Decreasing Fidelity to IMO-EEDI
Reference lines using IMO guidelines

Study target

$R^2 > 0.85$

Too low $R^2$ value

$P_{AE}$ calculated as cargo ship

$P_{AE}$ calculated as pax ship

$P_{AE}$ data from IHS database

GT as Capacity

Too low $R^2$ value

$y = 1816.2x^{0.445}$

$R^2 = 0.746$

$y = 1626.7x^{0.4294}$

$R^2 = 0.7525$
Reference line using IMO guidelines
(without outliers - \( P_{AE} \) as per cargo ships’ formula)
Attempts to improve \( R^2 \)
Reference line using IMO guidelines
(without outliers - $P_{AE}$ as per Ro-Pax 0.35 $P_{AE}$ ships’ formula)
Attempts to improve $R^2$

EEDI 0.35 $P_{AE}$ IHS No Outliers

$y = 1959.4x^{0.436}$
$R^2 = 0.8039$
Reference lines using IMO guidelines
(Attempts to improve $R^2$)

Only ships with high number of passengers, i.e., ships carrying mainly truck drivers have been excluded.

$GT > 3.000$
Reference line using IMO guidelines (attempts to improve $R^2$)

EEDI in respect of ratio main engine power installed in respect of the engine power resulting from Admiralty formula

$$\frac{P_{ME}}{P_{ADM}} = 500 \times \frac{P_{ME}}{(0.6 \times GT)^{2/3} \times V^3}$$

$1 < \frac{P_{ME}}{P_{ADM}} < 2$

$y = 354.9x^{0.28}$

$R^2 = 0.218$
Empirical tentative to separate the whole population into two more homogeneous samples

Reference lines using IMO guidelines (attempts to improve $R^2$)
Reference line using IMO guidelines (attempts to improve $R^2$)

Tentative to separate the whole population into daily service ships and overnight.
Capacity = A * cars number + B * trucks number + C * (passengers number - trucks number - 3 * cars number)

Alternative definition of Capacity (Dwt, GT eq)

DWT as capacity
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  - GT as capacity
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT as capacity, formula in accordance with MEPC.1/ Circ 681</td>
<td>0.746</td>
</tr>
<tr>
<td>Previous line without outliers</td>
<td>0.72</td>
</tr>
<tr>
<td>Ships characterized by GT&gt;3.000</td>
<td>0.445</td>
</tr>
<tr>
<td>Ships with only passengers onboard (no only truck drivers)</td>
<td>0.529</td>
</tr>
<tr>
<td>$1&lt;P_{ME} / P_{ADM}&lt;2</td>
<td>0.218</td>
</tr>
<tr>
<td>Upper sample (empirical separation law)</td>
<td>0.664</td>
</tr>
<tr>
<td>Lower sample (empirical separation law)</td>
<td>0.688</td>
</tr>
<tr>
<td>Daily service</td>
<td>0.738</td>
</tr>
<tr>
<td>Overnight service</td>
<td>0.487</td>
</tr>
<tr>
<td>DWT as capacity</td>
<td>0.645</td>
</tr>
<tr>
<td>GT eq as capacity (function of cars, trucks and passengers number)</td>
<td>0.288</td>
</tr>
</tbody>
</table>
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  - GT as capacity
Considerations

- The sample is characterized by wide range in terms of GT, power, speed
- The type of ships considered need to face problems of competitiveness with other means of transportation

New idea:
calculation of EEDI considering the power necessary for each ship to reach a defined speed.
Even if it could be true (considering only ship emission reduction) that …

One ship at full speed

“x” Cargo quantity in “y” time
“z” Tons CO$_2$
Permanence of cargo on board = “y”

Two ship at half speed

Same ratio Cargo quantity / Time
Significant reduction of CO$_2$ emissions
Double time of permanence on board
… the same concept is not applicable to ro-ro pax ships
Actual ro-ro pax design speed is studied to achieve a time of permanence on board competitive in respect of other transport means.

Will the duplication of the time on board maintain ro-ro pax competitive in respect of other transport means?

Is this solution in the way of a global CO₂ reduction?

<table>
<thead>
<tr>
<th>Comparison of CO₂ emissions between different modes of transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo vessel over 8,000 dwt</td>
</tr>
<tr>
<td>Cargo vessel 7,000-8,000 dwt</td>
</tr>
<tr>
<td>Heavy truck with trailer</td>
</tr>
<tr>
<td>Air freight (750 kg)</td>
</tr>
</tbody>
</table>

Source: RMT Sweden
Optimal Baselines for Optimal Ships Approach

Each baseline is recalculated by using all the population in the sample

The re-calculation is done by answering to the question:

What would be the installed power for a generic ship in the population to sail at a different speed (the speed for which the baseline is being re-calculated) respect to its own design speed?

By knowing the power needed you can re-establish a new “virtual” sample population and hence the new baseline that is the state of the art for that speed based on the actual fleet

You will then compare your new built ship against the new state of the art baseline for that design speed and you must be better than that!
1. A ship's type population is identified;
2. The Admiralty law is chosen to model the relationship Power versus Speed (see formulation below);
3. The Ac coefficient is calculated on the base of the LBP and the service speed as declared in the IHS (Formula (2) below);
4. The Ac is then used to estimate the Power by using GT and again service speed as declared in the IHS;
5. The Power estimated for each ship is the power needed for her to sail at that particular selected speed.
6. A baseline is then calculated by taking the so generated Power and the chosen speed.

\[ A_c = 26 \left( \sqrt{L} + 150/V_k \right) \]
\[ Power = \frac{\left( A^2 \cdot \frac{V_k^2}{s} \right)}{A_c} \]

Munroe-Smith (1975)
Admiral Law

\[ \text{Estimated Index Value} = 3.1144 \cdot \frac{190 \cdot \sum_{i=1}^{NME} P_{MEi} + 215 \cdot P_{AE}}{\text{Capacity} \cdot V_{ref}} \]
By applying the previous steps is possible to define a baseline per Kn as the one shown below.
Reference lines evaluated for each $kn$ (from 15 to 30)

<table>
<thead>
<tr>
<th>Kn</th>
<th>a</th>
<th>c</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>5043</td>
<td>-0.636</td>
<td>0.9267</td>
</tr>
<tr>
<td>16</td>
<td>6053</td>
<td>-0.642</td>
<td>0.9258</td>
</tr>
<tr>
<td>17</td>
<td>7182</td>
<td>-0.648</td>
<td>0.9249</td>
</tr>
<tr>
<td>18</td>
<td>8343</td>
<td>-0.653</td>
<td>0.924</td>
</tr>
<tr>
<td>19</td>
<td>10376</td>
<td>-0.657</td>
<td>0.9233</td>
</tr>
<tr>
<td>20</td>
<td>11303</td>
<td>-0.661</td>
<td>0.9226</td>
</tr>
<tr>
<td>21</td>
<td>11928</td>
<td>-0.664</td>
<td>0.9226</td>
</tr>
<tr>
<td>22</td>
<td>14683</td>
<td>-0.667</td>
<td>0.9216</td>
</tr>
<tr>
<td>23</td>
<td>16659</td>
<td>-0.67</td>
<td>0.9212</td>
</tr>
<tr>
<td>24</td>
<td>18588</td>
<td>-0.672</td>
<td>0.9209</td>
</tr>
<tr>
<td>25</td>
<td>20742</td>
<td>-0.674</td>
<td>0.9207</td>
</tr>
<tr>
<td>26</td>
<td>22458</td>
<td>-0.677</td>
<td>0.9203</td>
</tr>
<tr>
<td>27</td>
<td>25460</td>
<td>-0.678</td>
<td>0.9202</td>
</tr>
<tr>
<td>28</td>
<td>28026</td>
<td>-0.679</td>
<td>0.9203</td>
</tr>
<tr>
<td>29</td>
<td>28073</td>
<td>-0.679</td>
<td>0.9203</td>
</tr>
<tr>
<td>30</td>
<td>33581</td>
<td>-0.682</td>
<td>0.9201</td>
</tr>
</tbody>
</table>

Original baseline coefficients

All speeds | 1852 | -0.449 | 0.7795
Thank you!