Understanding the Energy Efficiency Operational Indicator:

An empirical analysis of ships from the Royal Belgian Shipowners’ Association

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Executive Summary
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Context and purpose of study

- Shipping is commonly cited as the most efficient transport mode. When expressed as a generalization (across all ship types), this is rarely disputed. However, recent discussions and attempts to quantify the more detailed energy efficiency characteristics of the existing ship fleet have been met with criticism. Objections to previous analyses have pointed to unrepresentative input data, limited real-world operational data to reflect actual operational conditions, and incomplete quantification of technical versus operational efficiency characteristics. Many of these objections are well-founded, due to the generally poor quality of data describing the existing fleet of ships and the wide-ranging parameters that influence the performance and therefore efficiency of ships in their day-to-day operation (as opposed to an artificial ‘calm’ sea or acceptance trial).

- Building on the previous work undertaken in 2009 by the Royal Belgian Shipowners’ Association (VITO, 2009), the RBSA would like to obtain further insights into ship efficiency and recent events in the industry since 2007 by examining individual ships as well as fleets’ data over this period. The insight gained from these analyses might be used to assist RBSA and other ship owners and stakeholders in understanding best practice for energy efficiency, the implications of different potential public domain indexing or MRV policy developments, formulating an evidence-based opinion on the merits of different operational energy efficiency indices, preparing for foreseeable future changes in the industry, and assisting in the development of cost-effective GHG policy for shipping at the IMO.

- To address these objectives, this study carries out a series of analyses on a set of owner-reported data, similar to the data that will be used to comply with the future legislation. As well as calculating the carbon emissions and values of EEOI for ships in the RBSA’s owner’s fleets, the study decomposed the EEOI into sub-indices (technical and logistics factors) and in terms of the contribution of the laden, ballast and port segments to EEOI for 94 ships in the bulk carrier, chemical tanker, container, liquefied gas tanker and oil tanker sectors over the period 2008-2014. Alternative indicators currently being considered at the IMO were also considered and compared to the EEOI results in order to discuss their respective merits both for understanding of the energy efficiency of shipping and comparing ships’ relative energy efficiency.

Key results of the study on the EEOI of the RBSA fleet
In general, we find that the EEOI decreases monotonically with size, but there is wide variation within a ship type’s size class. For example, DWT, a proxy for technical efficiency, only explains 46% of the variation in EEOI for the sample of bulk carriers over the period 2008-2013. This variation as shown in Figure 1 is mostly explained by the logistics parameters.

![Figure 1 Annual EEOI and DWT for Bulk carrier by size](image)

- Speed affects both the numerator of the EEOI (fuel consumption) and the denominator (transport work), but in differing degrees. In general, an increase in ship speed leads to a greater increase in fuel consumption than transport work, due to the non-linear relationship between fuel consumption and speed. The significance of this is that a marginal change in speed will have a greater effect on the EEOI than a marginal change in transport work.
- Carbon emissions, as represented in the numerator of the EEOI, are being driven by a ship’s movements at sea, which account for about 90% of carbon emissions, whereas emissions in port represent less than 10% of the total emissions.
- Calculations of EEOI made using data collected from owners by the RBSA show moderate decreases (improvements) in the EEOI during the period of the study (2008-14). This was associated with a consistent decrease in the
operational speed of ships in the sample (for an example, see Figure 3), which decreased during the period of this study across all ship types and size categories.

![Figure 2 EEOI and logistics factors - size 5](image1)

*Figure 2 EEOI and logistics factors for bulk carriers size range 100,000-199,999 dwt; size sample: 8 ships.*

- The trends for both allocative utilization (the ratio of laden days to total sea days) and payload utilization (total mass of cargo divided by the DWT) differ and in many cases showed a deterioration; along with the lower speed leading to fewer voyages per year, reduced annual transport work. This reduction in annual transport work partially offset the operational efficiency improvements obtained by slow-steaming related reductions in fuel consumption.

- In terms of the logistics factors (allocative utilization, payload utilization and a speed factor), there is little evidence of correlation between the EEOI and any one logistics factor; for all of the types and sizes considered, variations in EEOI can be explained only by considering contributions from a combination of the logistics factors. For example, Figure 3 shows that the increase in EEOI in 2010 for a sample of Capesize ships can be explained by the decrease in allocative utilization and payload utilization, which offset the speed effect.
Calculating the EEOI using data collected (noon report and cargo data) by ship owners proved to be a time-consuming task, due to the fact that each owner has a different internal system for collecting the data which is not designed to calculate EEOI, and also because the data contained missing and erroneous fields which had to be validated for consistency.

**Inferring a ship's technical efficiency from measurements of the parameters used in the EEOI calculation**

- A theoretical approach is proposed to isolate the ship's technical efficiency (the fuel consumption in a set of reference conditions), from its operational efficiency, by controlling for the influence of the logistics factors. The resulting estimated technical efficiency is referred to as the Energy Efficiency Technical Indicator (EETI).
- Calculations were undertaken using the data for the RBSA fleet showing the variability in the EETI among ships within a given size category and also for a fleet of ships over time.
- The expectation that EEOI should have greater variability (from one ship to another), than the EETI, which varies according to the hull, propulsion and machinery condition changes, and metocean conditions, was generally observed to be true for the RBSA fleet. It appears to be a particularly valid expectation for the larger ships (e.g. Capesize bulk carrier), which is also expected since these ships are more likely to be technically homogenous to begin with.
- The estimated trend in EETI appears consistent with expectations that performance is likely to gradually deteriorate over time (e.g. coating and fouling deterioration, propeller damage, engine wear). Figure 4 illustrates that this implies that improvements in the EEOI are being driven by the logistics factors in spite of this underlying technical efficiency deterioration – mainly due to extensive implementation of slow steaming.
However, as there are some other trends that are well correlated with the EETI (e.g. reducing speed, increasing EETI) it is possible that the trend in the EETI is the result of an inaccuracy in its estimation (e.g. due to an inadequacy in the power law of three used in the speed factor derivation). Further work is required to analyze the trends in speed and test the approach with further data, in order to understand the reliability and accuracy of the indicator.

**Alternative metrics to EEOI for estimating the operational efficiency of shipping**

For each ship type and size class, three alternative operational energy efficiency indices were calculated: the Japanese proposal (EEJI) at IMO (use of dwt.nm instead of transport work), the US proposal (EEUSI) to use energy per unit of time at sea, and the proposal to use fuel consumption per unit of distance travelled. Along with EEOI, these indicators are commonly referred to as energy efficiency indices. However, those for which the CO₂ emissions are calculated (EEOI, EEJI) are more correctly referred to as carbon intensity indicators. This becomes more important when comparing the indicators, and in this instance the term ‘carbon intensity’ is sometimes used instead of ‘energy efficiency’.

*Figure 3 EETI and logistics factors for bulk carriers size range 100,000-199,999 dwt; size sample: 8 ships.*
• The data from the RBSA fleet show varying levels of trend agreement/disagreement. Significantly, it is often the case that the three alternative indicators produce different trends to EEOI. This shows that a) no alternative energy efficiency metric is a reliable proxy to EEOI and b) the choice of energy efficiency metric is a function of what information is believed to be of greatest importance. Of the indicators considered, the EEOI is the only indicator that represents the true carbon intensity of the transport work done (when measured in t.nm’s), all other indicators approximate transport work in some way. This can be seen in Figure 4, in which the EEOI upticks in 2010 whereas the other indices show decreases.

Figure 4 EEOI and alternative indicators for bulk carriers size range 100,000-199,999 dwt; size sample: 8 ships.

Relating the EEOI to technical measures and market conditions

• From interviews with the companies owning bulk, LPG, and container ships, there were no major technical interventions during the period of the study. However, the company owning bulk carriers was taking operational measures such as economical (slow) steaming and voyage optimization. Given the bleak prospects for the shipping industry at the end of 2008 (the first year of the study’s time period) and high fuel prices through to 2013,
ships were slow steaming for all ship types in the study until at least 2013 as the cost savings were more valuable than saving time.

- Payload utilization also followed a similar declining trend in line with the deterioration in market conditions, but there was no obvious pattern in allocative utilization. This could be due to different strategies for owners, with some owners minimizing ballast distance whereas other owners were forced to search for employment by ballasting farther. Further work is required to investigate these patterns, as we did not account for changing trade (demand) patterns which could also drive changes in allocative utilization.

- Analyzing by contract type showed that the laden EEOI was lower when a ship was operated on the spot market compared to time charter for the majority of size classes in the dry bulk carrier sample for which there was contract data. This points to the importance of split incentive problems in the shipping industry, in which the owner may not be in control of the operation and hence efficiency of the ship for the majority of the ship's operating days.

**Conclusions**

- Technical and logistics factors are the key drivers of the Energy Efficiency Operational Index (EEOI). This paper has mathematically decomposed the EEOI into sub-indices in order to understand the drivers of the index. We find that there is a relationship between technical efficiency (EEDI) and EEOI across different ship sizes, but there is a wide dispersion of EEOI values within a ship size class. This can be explained by the variation in logistics factors, with little evidence of correlation between EEOI and any one logistics factor. For all of the types and sizes considered, variations in EEOI can be explained only by considering contributions from a combination of the logistics factors.

- We find that consistently across all ship types and size categories, speed decreased during the period of this study, trends for both allocative and payload utilization differ and in many cases showed deterioration in utilization which counteracts operational efficiency improvements obtained by slow-steaming. We also found significant differences in the laden EEOI when a ship was operated on the spot market compared to time charter for a subset of the ships for which there was contract data, resulting in higher laden EEOI for ships on time charter. This points to the importance of principal agent problems in the shipping industry, in which the owner may not be in control of the operation and hence efficiency of the ship for the majority of the operation of a ship.

- We compared the EEOI and alternative indicators proposed at the IMO. For each of the different ship types and sizes, the alternative operational energy efficiency indices show varying levels of trend agreement or disagreement. Significantly, it is often the case that the three alternative indicators produce different trends to EEOI. This shows that no alternative energy efficiency
metric is a reliable proxy to EEOI and the choice of energy efficiency metric is a function of what information is believed to be of greatest importance. Of the indicators considered, the EEOI is the only indicator that represents the true carbon intensity of the transport work done (when measured in t.nm’s), all other indicators approximate transport work in some way.