A FRAMEWORK FOR REAL-TIME MONITORING OF CO_2 EMISSIONS FROM MARINE VESSELS

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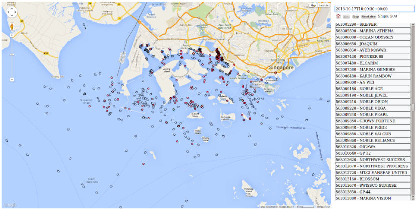
Motivation

Marine Environment Protection Committee (MEPC), the Energy Efficiency Operating Index (EEOI) is proposed for the first time to improve operational energy efficiency



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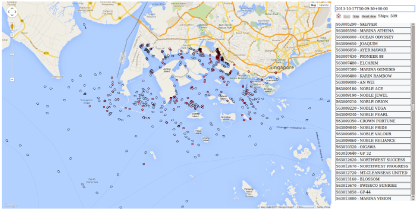

- Index must capture CO_2 emissions;
- The indicator must be expressed in terms of ratio with respect to the *transport work*

Objective of the research

Main Challenges towards vessels benchmarking

(1) Partial information, (2) noise in the measurements, (3) lack of analytical models to represent marine vehicles consumption.

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- International Maritime Organization

Energy Efficiency Estimation: preliminaries

In general it is a ratio between the consumption and the transport supply.

1. **Technical** Efficiency: characterizes a vessel "as designed" assuming it is loaded up to its maximum capacity;
2. **Operational** Efficiency: considers the vessel in its operational conditions and uses information concerning speeds;
3. **Nominal** Efficiency: different from the previous indicator, uses nominal coefficients for capacity utilization.

We focus on the *operational efficiency*.

Operational Efficiency

Is the ratio between the actual CO_2 emission and the actual transport supply $OE = \frac{C}{S} = \left[\frac{g_{CO_2}}{ton \cdot nmi}\right]$.
In MPEC a three phase method has been proposed to measure *any* energy efficiency indicator and to guide towards the establishment of a unique agreed standard:

- Phase 1: Data collection;
- Phase 2: Pilot Testing;
- Phase 3: Adoption of the procedure of Mandatory Standard.

Energy efficiency methods: a comparison

The different energy efficiency indicators can be compared based on:

- C1 Ease of adoption;
- C2 Feasibility of real-time monitoring;
- C3 Sensitivity to factors not considered in the index formulation;
- C4 Comparability across different modes of transport;
- C5 Completeness as energy efficiency indicator.

Index Comparison

Indicator	Source	C1	C2	C3	C4	C5
EEOI (RT-EEOI)	International Maritime Organisation (MEPC.1/ Circ.684)	Hindered by confidential information	Hindered by the real time tracking of the cargo mass, real time indicator is available	Weather conditions as well as economic conditions might affect the vessels efficiency	High	High
EHS	United States (MEPC.64/5/6)	Strong within the USA	Hindered by non-standard definitions contained in the index	-	Absent	High
ISPI	European Maritime Safety Agency	Hindered by the need to estimate EIV	Difficult as it requires information on the route which is not available	Weather conditions as well as economic conditions might affect the vessels efficiency	Absent	High
FORS	Germany	Easy to Implement	Possible with AIS data	Low since the measure is standardized	High	Low
NEEOI	Republic of Korea (MEPC 61/5/29)	Easier than EEOI due to the omission of the real cargo mass	Easier than EEOI as does not require to track cargo mass	Weather conditions as well as economic conditions might affect the vessels efficiency	High	Low, as it does not capture capacity utilization

RTEEOI

The Energy Efficiency Operating Index (EEOI) is defined as ratio between the mass of emitted CO_2 per *transport work unit*:

$$EEOI = \frac{\sum_j FC_j \cdot C_{F_j}}{m_{cargo} \cdot D} \tag{1}$$

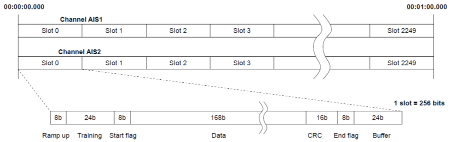
- j is the fuel type;
- FC_j is the mass of consumed fuel $[ton]$;
- C_{F_j} is the CO_2 mass conversion factor for fuel type j;
- m_{cargo} is the carried cargo mass;
- D is the distance in nautical miles $[nmi]$ under m_{cargo}.

The RT-EEOI extends this definition as:

$$RT - EEOI = \frac{\sum_j R_{FC_j} \cdot C_{F_j}}{m_{cargo} \cdot V} = \left[\frac{g_{CO_2}}{ton \cdot nmi}\right] \tag{2}$$

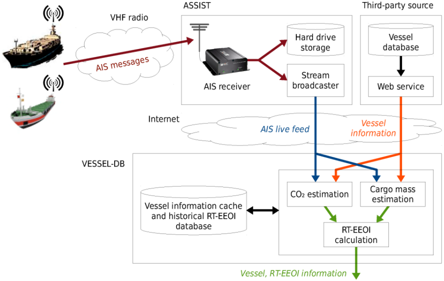
AIS for vessels monitoring

AIS technology is the most developed technology in the maritime environment and it has substantially enhanced navigation safety. It is based on the VHF radio signal and it has been made mandatory by the International Maritime Organization's (IMO) Safety of Life at Sea (SOLAS) convention



AIS can be replaced by any advanced sensing system. This will improve the effectiveness, reliability and accuracy of the proposed framework.

Architecture



- Data are gathered from online data sources and ASSIST;
- Information are collected in VESSEL–DB which is refreshed;
- A set of fast algorithms is used to compute the final index.

Data Model

- Vessel Information (static);
- Vessel Status (dynamic);
- Monitoring Information (derived);

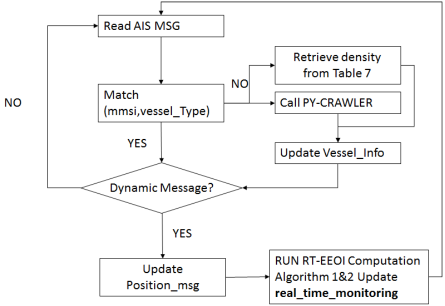
Vessel's characteristics

Field	Unit of Measure	Source	F(ree)/P(ay)
mmsi	-	AIS	F
Vessel_type	-	AIS	F
TPC(*)	[ton/cm]	web	P
ρ (*)	[kg/m^3]	Table 8	F
δ^N (*)	[m]	web	P
γ^N (*)	-	web	P
Beam	[m]	AIS	F
Year Built	-	web	F
Deadweight υ	[ton]	web	F
γ(*)	[ton]	web	F
EngineType	-	Table 5	

Vessel's navigational status

Field	Unit of Measure	Source
mmsi	-	AIS
timestamp	[date]	AIS
Navigation_Status(*)	-	AIS
v (*)	[knots]	AIS
Rate of Turn	[degrees/min]	AIS
Longitude	[degrees]	AIS
Latitude	[degrees]	AIS
δ^{RT}	[m]	AIS

Computational Procedure



- Data Filling through real-time crawling;
- CO_2 Estimation algorithm;
- Cargo Mass Estimation.

CO_2 Estimation algorithm

Algorithm 1: CO_2 Estimation Procedure

```
1  if Navigation Status == 0 ∪ 8 ∪ 15 then
2      if v ≤ 64.3%v^D then
3          State = Maneuver;
4          Go To Step 24
5      end
6      else
7          State = Cruising;
8          Go To Step 26
9      end
10 end
11 if Navigation Status == 1 ∪ 3 ∪ 5 then
12     if Navigation Status == 1 then
13         State At_Anchor
14     end
15     if Navigation Status == 3 then
16         State Maneuver
17     end
18     if Navigation Status == 5 then
19         State Moored
20     end
21     Go To Step 24
22 end
23 Computation C1:
24     R_FCj ≃ c_Fj · λ · P ;
25 Computation C2:
26     R_FCj ≃ c_Fj · (v/v^D)^3 · η · P
```

Step 24: $R_{FC_j} \simeq c_{F_j} \cdot \lambda \cdot P$;

Step 26: $R_{FC_j} \simeq c_{F_j} \cdot \left(\frac{v}{v^D}\right)^3 \cdot \eta \cdot P$

Several models have been proposed to estimate the R_{FC_j}:

- numerical models based on offline learning over large data sets [Yao et al. 2012, Du et al. 2015];
- empirical models from laboratory experiments.

We adopt an empirical model, but other models can be applied as well as pure sensing if available.

Cargo Mass Estimation

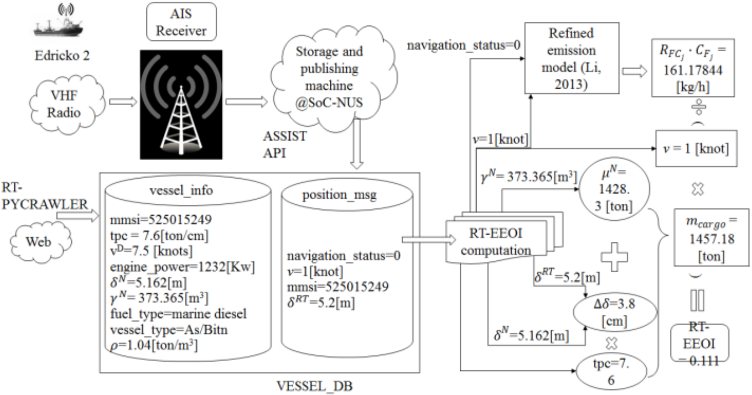
- $\Delta\delta$: variation of the draft;
- γ^N: Unit-less index related to the ship overall internal volume, divided by 100 cubic feet;
- μ^N: mass of the cargo carried when the draft reaches the maximum static draft.

Algorithm 2: Generic Procedure for Real Time Monitoring of RT–EEOI

Data Collection: Connect to web source through PY-crawler and connect to ASSIST;
Monitoring State =1 ;
while *Monitoring State == 1* **do**
  if $msgType = 1 \cup 2 \cup 3 \cup 18 \cup 19$ **then**
    record `Position_msg`
    Use the `Navigation_status` and apply Algorithm 1
    Return R_{FC_j} and the Emission Rate $R_{FC_j} \cdot C_{F_j}$;
    Compute $\Delta\delta = \delta^{RT} - \delta^N$;
    Compute $\gamma^N \leftarrow \gamma^N \cdot c_\gamma$;
    Compute $\mu^N = \gamma^N \cdot \rho^c$;
    $m_{cargo} = \mu^N + TPC \cdot \Delta\delta$;
    $RT - EEOI = \frac{R_{FC_j} \cdot C_{F_j}}{v \cdot m_{cargo}}$
  end
end

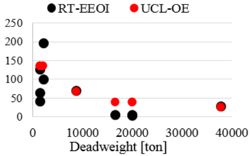
Validation of the Procedure

We ran the architecture receiving and analyzing AIS messages on February 23rd 2015 in the time window 12:00-7:00PM. Data are related to the product tanker with MMSI 525015249.

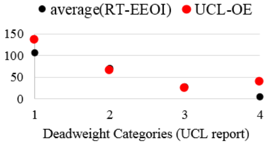


Validation of the Procedure - UCL Report

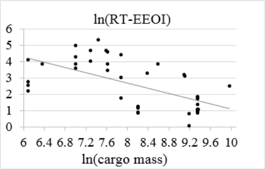
We compared our RT-EEOI with the statistics presented in the UCL Energy Institute Report [2009].



Real time (RT-EEOI) and Average (UCL_OE) efficiency against deadweight for Product Tankers



Average RT-EEOI per deadweight category against the estimated UCL-OE for Product Tankers



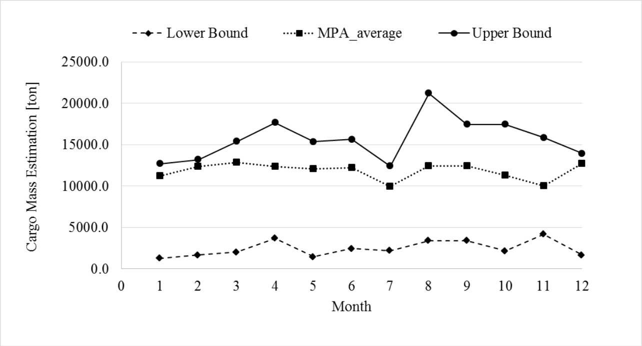
Validation of the emission model

the AIS data from Feb $5th$2014 from the West sector of the Singapore Strait, during four different time windows during the day:[00:00 - 01:00; 06:00 - 07:00; 12:00 - 13:00; 18:00 - 19:00].

- The emission is in $[42.3, 80.9]\,[tonCO_2]$;
- The amount of near port CO_2 emission is $(1/4) \cdot (59.13 + 60.75 + 42.39 + 80.1) = 60.5[ton]$;
- The total emission amount will be approximately $60.5 \cdot 24 \cdot 365 = 530,000[ton]$, which represents 1.36% of the total bunker–related consumption for Singapore.

Validation of cargo mass estimation model

We compare the estimated cargo mass against the data for the specific category of crude oil/oil products tankers for the year 2014 published by the Maritime Port Authority (MPA) of Singapore. The data is publicly available at www.mpa.gov.sg.



Conclusions

Contribution

Framework for real time performance monitoring for encourage mandate information sharing.

- Real Time learning/computing structure;
- Results are quite promising.

Highlights

- Application provides the possibility to **monitor** and **benchmark**;
- It represents a fundamental step towards optimal real-time control of vessel operations;
- This work is a further case of successful exploitation on Lian Cheng.

Thank You