Shipping Emissions and Air Quality Impacts in East Asia

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East Asia Is a Significant Source in Seaborne Trade

Asia's share of world seaborne trade reached 38.7% and 49.4% for goods loaded and unloaded in 2013.

8 of the Top 10 global container ports are located in East Asia in 2014.

World Shipping Council
Based on the Demand of the Atmospheric Pollution Control in China

**Beijing-Tianjin-Hebei Heavy Pollution Forecast** issued by the China Meteorological Administration and the Ministry of Environmental Protection for the first time on Feb 21, 2014

Legend
- **Moderate**
- **Heavy**
- **Severe**
Disaggregate Dynamic Method Based On AIS Data

\[ E_{total} = E_{propulsion} + E_{auxiliary} + E_{boiler} \]

\[ E_{propulsion} = MCR \cdot EF_{propulsion\_base} \cdot \sum_{T} LF_{t} \cdot A_{LF,t} \cdot \Delta T_{t} \]

\[ E_{auxiliary} = \cdot EF_{auxiliary} \cdot \sum_{T} (P_{auxiliary,i,j} \cdot \Delta T_{t}) \]

\[ E_{boiler} = EF_{boiler} \cdot \sum_{T} (P_{boiler,i,j} \cdot \Delta T_{t}) \]

- Literature Research of Shipping Emission Factors
- Static Data
  - MMSI
  - Ship Type
  - Flag
  - Parameters
- Dynamic Data
  - Activity
  - Speed
  - Time
  - Navigation
  - Position
  - Feature
- Emission Factors
  - Database of Emission Factors
  - Base
  - Fuel Type
  - Fuel Sulfur
  - Adjust Factor
- Bottom-up Emission Model
  - Temporal and Spatial Allocation
- Regional Shipping Emission Inventory

✓ Real-time power instead of traditional power statistics
In this study, 65903 vessels by Gradient Boosting Regression Tree

- **Lloyd’s Register**
- **China Classification Society**
- **Other sources**

Static ship data includes vessel type, rated engine speed, rated engine power, length, width, height, design max speed, dead weight tonnage (dwt), maximum draught, build year, etc.

In this study, all vessels are divided into 10 OGV types:
- Auto Carrier
- Bulk Carrier
- Container Ship
- Cruise Ship
- General Cargo
- Miscellaneous
- Oceangoing Tugs/Tows
- RORO
- Refrigerator ship
- Tanker

**Static Ship Data**
Lloyd's data is more suitable for Europe and the United States. Many of our ships are registered in other countries.

Increase Data Value

- **Original Data**
- **Complementary Data**

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Original Data</th>
<th>Complementary Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>total no. of data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rated power</td>
<td></td>
<td></td>
</tr>
<tr>
<td>design speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>deadweight tons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rpm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>built year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nationality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>width/draught</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEU</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Optimize Representation

- 4761 container ships, accounting for 95.0% of a world total of 5014
- New ship types such as salvage boats, sludge cleaners and special vessels
98% of the intervals: less than 6 minutes ---- short enough.

Duplicate messages ----- Time Sequences Method.
## AIS statistics in East Asia and in the other studies

<table>
<thead>
<tr>
<th>Ship category</th>
<th>Ship number&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Ratio of in service&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Ships in service</th>
<th>ships observed on AIS</th>
<th>% of in-service ships observed on AIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Carrier</td>
<td>70</td>
<td>0.93</td>
<td>65</td>
<td>60</td>
<td>92%</td>
</tr>
<tr>
<td>Bulk Carrier</td>
<td>1,511</td>
<td>0.93</td>
<td>1,405</td>
<td>1,208</td>
<td>86%</td>
</tr>
<tr>
<td>Container Ship</td>
<td>524</td>
<td>0.93</td>
<td>487</td>
<td>391</td>
<td>80%</td>
</tr>
<tr>
<td>Cruise Vessel</td>
<td>2</td>
<td>0.93</td>
<td>2</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>General Cargo</td>
<td>1,172</td>
<td>0.93</td>
<td>1,090</td>
<td>764</td>
<td>70%</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1,543</td>
<td>0.96&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1,481</td>
<td>649</td>
<td>44%</td>
</tr>
<tr>
<td>Tugboat</td>
<td>367</td>
<td>0.96&lt;sup&gt;c&lt;/sup&gt;</td>
<td>352</td>
<td>252</td>
<td>72%</td>
</tr>
<tr>
<td>RORO</td>
<td>440</td>
<td>0.93</td>
<td>409</td>
<td>344</td>
<td>84%</td>
</tr>
<tr>
<td>Reefer</td>
<td>126</td>
<td>0.93</td>
<td>117</td>
<td>35</td>
<td>30%</td>
</tr>
<tr>
<td>Tanker</td>
<td>1,387</td>
<td>0.93</td>
<td>1,290</td>
<td>1,007</td>
<td>78%</td>
</tr>
<tr>
<td>Sum: Transport ships</td>
<td>5,232</td>
<td>0.93</td>
<td>4,866</td>
<td>3,809</td>
<td>78%</td>
</tr>
<tr>
<td>Sum: Non-Transport ships</td>
<td>1,910</td>
<td>0.96</td>
<td>1,833</td>
<td>901</td>
<td>49%</td>
</tr>
</tbody>
</table>

<sup>a</sup> Number of ships registered in East Asia countries; <sup>b</sup> Data is for 2012 transport ships, referenced from the Third IMO GHG study for 2012<sup>7</sup>; <sup>c</sup> Data is for 2012 non-transport ships, referenced from the Third IMO GHG study for 2012<sup>7</sup>. 
Fuel types and sulfur contents

Fuel types

- LNG Otto-cycle engine vessels
- HFO
- MDO/MGO
- Other vessels
- Harbor service vessels, such as work vessels, tugs, crew boats, etc.

Fuel sulfur contents in this study

- No specific Sulfur control regulation was assigned in this area as mandatory in 2013.
- Sulfur content for HFO: 2.43%, MDO/MGO: 0.13%

IMO, MEPC 67/20, 2014
Emission factors for different engines

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Fuel type</th>
<th>Tier</th>
<th>Model Year</th>
<th>PM</th>
<th>NOx</th>
<th>SO₂</th>
<th>CO</th>
<th>NMVOC</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSD</td>
<td>HFO</td>
<td>Tier 0</td>
<td>≤ 1999</td>
<td>1.335</td>
<td>18.1</td>
<td>9.261</td>
<td>0.54</td>
<td>0.6</td>
<td>607</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>MSD</td>
<td>(2.43% sulfur content)</td>
<td>Tier 1</td>
<td>2000-2010</td>
<td>1.335</td>
<td>17</td>
<td>9.261</td>
<td>0.54</td>
<td>0.6</td>
<td>607</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>SSD</td>
<td>MDO/MGO</td>
<td>Tier 0</td>
<td>≤ 1999</td>
<td>0.199</td>
<td>17.0</td>
<td>0.515</td>
<td>0.54</td>
<td>0.6</td>
<td>607</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>MSD</td>
<td>(0.13% sulfur content)</td>
<td>Tier 1</td>
<td>2000-2010</td>
<td>0.199</td>
<td>16.0</td>
<td>0.515</td>
<td>0.54</td>
<td>0.6</td>
<td>607</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>SSD</td>
<td>Sulfur content</td>
<td>Tier 2</td>
<td>2011–2015</td>
<td>1.335</td>
<td>15.3</td>
<td>9.261</td>
<td>0.54</td>
<td>0.6</td>
<td>607</td>
<td>0.031</td>
<td>0.012</td>
</tr>
<tr>
<td>MSD</td>
<td></td>
<td></td>
<td>2011–2015</td>
<td>1.330</td>
<td>11.2</td>
<td>10.215</td>
<td>0.54</td>
<td>0.6</td>
<td>670</td>
<td>0.034</td>
<td>0.01</td>
</tr>
<tr>
<td>Otto</td>
<td>LNG</td>
<td>na</td>
<td>all</td>
<td>0.03</td>
<td>1.3</td>
<td>0.003</td>
<td>1.3</td>
<td>0.5</td>
<td>457</td>
<td>0.018</td>
<td>8.5</td>
</tr>
</tbody>
</table>

a b c mean Slow speed diesel engine, Medium speed diesel engine and Otto-cycle LNG-fueled engine, respectively.
d IMO Tier 0 refers to all ships constructed prior to 1st Jan, 2000 which did not have an IMO Tier requirement at the time of construction.

Emission factors for main engine, g/kW· h

Emission factors for different engines are from:

1. Third IMO Greenhouse Gas study
2. IMO study
3. Lack et al
4. Third IMO Greenhouse Gas study 2014
5. EEA
6. EPA
Temporal and spatial distribution and regulatory effects of emissions from marine vessels' activities in East Asia.
Results: Growth of Shipping Emissions in East Asia

Seaborne trade: 2.62 times from 2003 to 2013 (90,003,566 to 236,285,057 TEU) in East Asia.

Emissions: 1.7 times for 2003 to 2020

Emission increases are not consistent for different pollutants (1.85 times for NOx, 2.7 times for SO₂, 1.7 for CO₂).

Our bottom-up method accounts for differences in regional distribution proxy, while previous word used the same spatial distribution proxy as CO₂.

1. Improvements in engine efficiency.
2. Missing some small ships.
Ship emissions of East Asia in 2013 are about 0.1%~5.3% of total emissions from all sources in 2008 (depending on pollutants).

Land-based emission inventory: the latest update in REAS 2.1.
Results: Ship emissions in China and regions

- China 2013 (Tg yr\(^{-1}\)):
  - \(\text{NO}_x\) 1.91 ± 0.01,
  - PM 0.164 ± 0.001
  - \(\text{SO}_2\) 1.30 ± 0.01
  - \(\text{CO}_2\) 86.3 ± 0.3

- 9%, 11%, 11%, 12%, 13% and 11% global shipping emissions of CO, NMVOC, \(\text{NO}_x\), PM, \(\text{SO}_2\) and \(\text{CO}_2\) (IMO report 2015)

Division method of port range

✓ Artificially divide berths (districts) in each port
  - Based on port maps and dynamic positioning of ships
  - 25 ports, 71 districts

✓ High-resolution AIS data to match the driving state of ships in port
  - Increase the AIS data resolution to get a high-resolution inventory
  - Port division and resolution of inventory: 0.01° × 0.01

✓ Match the emissions of auxiliary engine and boiler in port

<table>
<thead>
<tr>
<th>Area</th>
<th>No. of Berths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core ports in BRA</td>
<td>10</td>
</tr>
<tr>
<td>Non-core ports in BRA</td>
<td>15</td>
</tr>
<tr>
<td>Core ports in YRD</td>
<td>23</td>
</tr>
<tr>
<td>Non-core ports in YRD</td>
<td>3</td>
</tr>
<tr>
<td>Core ports in PRD</td>
<td>13</td>
</tr>
<tr>
<td>Non-core ports in PRD</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>71</strong></td>
</tr>
</tbody>
</table>

Berth division and dynamic positioning of ships in Yantai Port

- Berth (with fuel change)
- Anchoring (without fuel change)
Results: Ship emissions in ports

23-147 times higher than from the Port of Los Angeles

Prediction method of ship emissions

Three Core Factors in Ship Emission Prediction

1. **Rated power → MCR**
   - Ship emissions are proportional to the rated power MCR

2. **Vessel calls**

3. **Fuel consumption of the fleet (requirements of fuel consumption of new ship by IMO)**
   - Changes of fuel consumption reflects engine technology improvement
   - The data for the emission factor under this scenario is missing
   - We use the improvement of fuel consumption to represent the impact of technological progress, and we think emissions are proportional to fuel consumption

Next: respective analysis of the impact of 3 core factors on ship emissions
Prediction of vessel calls growth

<table>
<thead>
<tr>
<th><strong>Data source</strong></th>
<th><strong>Data input</strong></th>
<th><strong>Data output</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical data + planning of each port</td>
<td>Port throughput for each year</td>
<td>Throughput of different ships for year 2013 and 2020</td>
</tr>
<tr>
<td>United Nations reports, EPA reports</td>
<td>Sharing rate of throughput for different ships from 2013 to 2020</td>
<td>Number of vessel calls of different ships for year 2020/2013</td>
</tr>
<tr>
<td>United Nations report</td>
<td>Average load tonnage for different ships from 2013 to 2016</td>
<td>Average deadweight for different ships in 2013 and in 2016</td>
</tr>
</tbody>
</table>

\[
\text{Number of Voyages}_i = \frac{\text{Total tonnes of cargo moved}_i}{\text{average DWT}_i \times \text{utilization rate}}
\]

Assuming that the no-load rate of each ship is constant, the number of vessel calls is determined by the **throughput** and the **average deadweight**

EPA, 2009; UNCTAD, 2012-2016; Regional development planning
Prediction of vessel calls growth

Prediction of throughput for different ships in each port
- Planning throughput (2020): 19 ports have target values with an annual growth rate; Other ports have an annual growth rate of 4% (from research of Ministry of Transportation)
- The sharing rate of throughput for different ships in 2013 and 2020: United Nations reports and EPA reports

From 2013 to 2020, the throughput in JJJ, the YRD and the PRD increased by 46%, 20% and 40%, respectively.

Some non-core ports are growing faster

Figure 2. Port throughput in JJJ, the YRD and the PRD:
(a) Port throughput projections from 2013 to 2020; (b) the proportion of core ports in 2013 and 2020.
Thank You!

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