Estimation, Validation, and Forecasts of Regional Commercial Marine Vessel Inventories
Forecast Inventories for 2010 and 2020

James Corbett, P.E., Ph.D.
Chengfeng Wang, Ph.D.

11 December 2006
West Coast SECA Team Meeting
California Air Resources Board
Sacramento, CA

Overview and Summary

- North American inventory for base-year
  - Best practices: activity-based inventory uses ship data and empirical spatial network
  - Most current power-based emission factors
- Power-based trends used for forecasting
  - First-order indicator of proportional change in emissions, adjusted for contr
- Forecasts are primarily extrapolations of BAU that can be bounded and/or adjusted
  - Validated by comparison with other modal trends and with ship trade-energy models
  - Validated by comparison at multiple scales
- Ship emissions growth rates are faster than GDP
- Future emissions with IMO-compliant SECA will be greater than base year emissions in 2002

Review of ARB Project Objectives

1. Provide spatially resolved baseline CMV inventory of emissions at regional scale
2. Evaluate port-based inventories for potential agreement, validation
3. Spatially forecast future CMV emissions
4. Forecast future-year ship emissions under potential SECA designation

ARB focus on West Coast U.S. coastlines; SECA Team focus … North America
Integrating top-down & bottom-up: Linking GIS with nonroad modeling

- We use 20 years of data to define (global) network
- We have “complete” North American data for port arrivals and departures & data for individual ships
- GIS tools are now sophisticated enough to assign trips to a network of routes
- We then follow “best-practices” for inventory
- Addresses major critique of top-down results
- Remaining limitations similar to regional studies

Building Empirical Network

- ~9000 segments & ~1700 ports
- ~170,000 ship trips/yr in North America

Base year 2002 inventory: applied network model (STEEM), activity based methods for “all” NA traffic
Validation: No systematic bias, but room to improve – toward convergence at all scales

We are interested to learn how port-based adjustments contribute to these insights.

Validation: No systematic bias, but room to improve – toward convergence at all scales

We are interested to learn how port-based adjustments contribute to these insights.

Forecasting North America CMV emissions

Task 3 Forecast how baseline emissions may change in future years.

Task 4 Forecast future-year ship emissions under a potential IMO-compliant SECA equal to or less than 1.5% S by weight.
Critical freight forecasting questions

- What are freight energy and activity patterns?
  - STEEM provides baseline (Tasks 1 and 2)
- What is forecast trend in energy needed?
- Where is future freight activity be located?
  - Each involves uncertainty and bounding
  - May be validated with some independence
  - Emerging convergence on current baseline
  - Improving spatial allocation of better estimates
  - Continuing work on future usage and location
  - Modal analyses need integration and coupling

Forecasting: a suite of options

- Follow national methods, growth factors for each vessel type
- Look at port-specific growth rates and consider ways to blend (weighted average, straight average, etc.)
- Develop detailed stories (scenarios) or extrapolate from past
- Look at trade routes, within GIS context
  - Route-specific growth rates
  - Enables more explicit forecasting for power, etc.
  - Could be adapted into a modeling tool

Premises from which to forecast freight

Choosing the Growth Proxy

- Emission factors units: g/kWh or kg/million tonne fuel
- Average emissions factors are 2nd order proxies
- Consider = 8 technology mixes (2^3 model)
- Energetic activity (load, speed, trans) = installed power (fuel scale)
- Work done = Frt * dist = mass and speed of ship
- Emission factors are 3rd order mixtures
- Type of ship = power but modified by hull design and speed
- Number of ship visits = speed but modified by route
- Conversation in two about ship (2^3 order)
- Large tonnage = power, size, speed, modified by capacity
- Other proxies include: TILs, GDP, other modes, $ values, etc.
- All power predictions of emissions that power-based

Comparison and Validation

- Define the forecast domain broadly through multiple perspectives on freight and economy
- Consider first principles: work-energy relationship
- Recognize heterogeneity at all scales
- Look for surprise, avoid overconfidence

We use 1st order indicators of emissions growth
Adjusted power-based trend averaged exponential and linear curve-fits to data.

Methodology compares well with others. Provides a bounding range within which BAU forecast may be expected.

Cargo Movement Growth (Global)

Containership energy use driven by strong growth in “heavy-leg” activity.

Note the significant activity to move empty containers. Trade-based models can account for this through utilization factors, etc.
Building a valid range of world forecasts
... starting with trade and energy

Energy Trends

Trade Trends

Implication: World (ocean) freight emissions on track to double before 2050 (pre-2030?)
Building a valid range of world forecasts … starting with trade and energy

Implication: World (ocean) freight emissions on track to double before 2050 (pre-2030?)

Insights from global comparison

- Extrapolating past data (with adjustments) produces a range of BAU trends that is bounded and reveals convergence; we may interpret convergence as describing a likely forecast.

- World shipping activity and energy use are on track to double by about 2030 (~2015 if one considers seaborne trade since 1985, ~2050 if one considers Eyring’s BAU trend). Growth rates are not likely to be reduced without significant changes in freight transportation behavior and/or changes in shipboard technology.

- Confirming earlier discussion, trends in installed power are clearly coupled with trends in trade and energy. This reinforces the analysis of installed power as a proxy for forecasting growth, not only for use in baseline inventory estimates.

Power-based growth rate summary for commercial ships 2002 -2020 (CAGR)

Growth rates for North America are generally higher than world growth
Similar (within 2%) across all scales and regions
One NA growth rate justified – trend uncertainty greater than regional variation

<table>
<thead>
<tr>
<th>Ports or Region</th>
<th>Emissions Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles/Long Beach</td>
<td>5.24%</td>
</tr>
<tr>
<td>Oakland/San Francisco</td>
<td>5.68%</td>
</tr>
<tr>
<td>New York/New Jersey</td>
<td>6.03%</td>
</tr>
<tr>
<td>California (all ports)</td>
<td>5.53%</td>
</tr>
<tr>
<td>U.S. West Coast</td>
<td>5.93%</td>
</tr>
<tr>
<td>U.S. National</td>
<td>5.86%</td>
</tr>
<tr>
<td>Canada</td>
<td>6.57%</td>
</tr>
<tr>
<td>Mexico</td>
<td>5.06%</td>
</tr>
<tr>
<td>North America (U.S., Canada and Mexico)</td>
<td>5.86%</td>
</tr>
</tbody>
</table>

Growth rates represent an average of exponential and linear extrapolations, in CAGR

Results and Insights

- Produced 2010 and 2020 forecast inventories
  - Used one North American growth rate for all regions
  - Adjusted for IMO-compliant NOx fleet introductions
  - No change assumed in average sulfur for BAU fuel
  - Power-based extrapolation assumes current improvements in efficiency continue without substantial changes in BAU

- Considered hypothetical SECA set to EEZ default

- Compared IMO-SECA future to BAU future
  - Compared also with base year results

Model domain and hypothetical SECA
IMO-compliant SECA (1.5% S) reduces future emissions from BAU … but not compared to base year

Robust insight, even using other growth rates
Different growth rates simply change when this is forecast to occur

Uncertainty and bounding

- **Base-year uncertainty** – addressed in Tasks 1, 2
- **Uncertainty in trend extrapolation** – bounded through validation and comparison discussion
- **Improvements could address**
  - Incorporation of additional detail for change drivers
  - Incorporation of signals to modify technological change
  - Inclusion of fleet response to potential action
- **Spatial limitations and opportunities for improvement**
**Next Steps**
- Recognize different growth rates and re-forecast spatially
- Consider policy and technology interventions
- Couple better with economics trends
- Go multimodal
- Expand globally

---

**Acknowledgments:**
Collaborators, sponsors, colleagues

- **STEEM Model and North American Inventory:**
  - California Air Resources Board, Council on Environmental Cooperation, EPA, other agencies
- Global inventory improvements and modeling:
  - Jeremy Firestone; James Winebrake; Clean Air Task Force; Prasad Kasibhatla
- NOAA Right Whale Research Grant; ICTC 2k2 team; US DOT Center for Climate Change; US DOT Maritime Administration

---

**Discussion welcome**