Evaluating the Environmental Attributes of Freight Traffic along the U.S West Coast

Geospatial Intermodal Freight Transport (GIFT) Model with Cargo Flow Analysis

Prepared for the California Air Resources Board
California Environmental Protection Agency
Contract No.: 07-314

James J. Corbett, University of Delaware
J. Scott Hawker, Rochester Institute of Technology
James J. Winebrake, Rochester Institute of Technology

Presented at the ARB Air Pollution Seminar Series
7 June 2011
Project Objective

- Quantify environmental impact of containerized freight movement in the West Coast Freight Gateway and Corridor
- Apply a GIS-based model modified to include California-specific inputs
- Demonstrate potential system improvements to achieve GHG reductions and address environmental issues related to freight transport

Source: U.S. Maritime Administration
Discussion Items

• Background on Freight Transport
• Reasons to Model Alternatives
• GIFT Model
• Research Methodology
• Results and Analysis
• Summary
Attributes of Freight Transport

FREIGHT TRANSPORT BACKGROUND
Transportation represents ~35% of GHG in U.S. ~6 Gt CO₂ emissions in U.S.; ~2 Gt transportation

Percentage of Energy-Related Transportation CO₂ Emissions by Mode, 2008

- Light-Duty Vehicles: 57.8%
- Commercial Light Trucks: 2.1%
- Bus Transportation: 1.0%
- Freight Trucks: 18.3%
- Rail, Passenger: 0.3%
- Rail, Freight: 2.2%
- Shipping, Domestic: 1.2%
- Shipping, International: 3.1%
- Air: 9.8%
- Military Use: 2.8%
- Lubricants: 0.3%
- Recreational Boats: 0.9%

Source: AEO 2009, Table 19.
The U.S. freight industry is dominated by Truck

Freight touches energy use, environmental quality, economic growth, congestion mitigation, and national security

Tons of Freight by Mode, 2007

- Truck: 79%
- Rail: 17%
- Water: 4%
- Air: 0%

Value of U.S. Freight by Mode, 2007

- Truck: 92%
- Rail: 4%
- Water: 1%
- Air: 3%

Source: 2007 Commodity Flow Survey Table 1
Freight Overview

- Energy use within freight mode is proportional to work done
- Carbon intensity (and other emissions) not symmetric across modes

Global and US Cargo Flows (Gt-km) by Mode (2005)
Goods Movement and GDP


For every trillion dollar increase in GDP, we expect an additional 242 billion ton-miles.

Source: Corbett and Winebrake, 2008.
Calculating Impacts from the Bottom Up

Calculators developed by RIT and the University of Delaware to support research activities under the Sustainable Intermodal Freight Transportation Research (SIFTR) program

MODAL MODELING OF POSSIBILITIES
Geospatial Intermodal Freight Transportation Model

THE GIFT MODEL
VISUALIZING GOALS
MODELING
ALTERNATIVES

Intermodal freight network optimization model to evaluate objective tradeoffs.
Developing resources for “tabletop” exercises with industry and agencies.
Evaluates performance against benchmarks and optimizes with respect to possible targets
Web-version in development.
How are we using GIFT?

• Table-top exercises with leaders in transportation
  – Modal experts and industry decision makers
  – Public infrastructure planners at regional and national levels
  – Environmental, energy interests in public and private sectors

infrastructure
fuels
technologies
operations
logistics
demand
The GIFT Model
Integrating the National Transportation Atlas Database (NTAD) Components

Each segment and spoke of the network contains temporal, economic, and environmental attributes—called “cost factors.”

Attribute values used to search for routes that minimize the total “Costs”
The Geospatial Intermodal Freight Transportation (GIFT) Model

- GIS-based optimization model
- Intermodal network (Road, Rail, Water and Facilities)
- Calculation of least time, least cost, least energy and least emissions (CO2, PM10, NOx, SOx, VOC) routes
- Tool to aid decision makers understand environmental, economic, energy impact of intermodal freight transportation and to compare trade-offs among various policy scenarios

**CO₂ Emission Comparison**

<table>
<thead>
<tr>
<th>Mode</th>
<th>CO₂ (kg/MTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck</td>
<td>500</td>
</tr>
<tr>
<td>Ship (DR)</td>
<td>400</td>
</tr>
<tr>
<td>Rail</td>
<td>300</td>
</tr>
<tr>
<td>Ship (EJ)</td>
<td>200</td>
</tr>
</tbody>
</table>

**Time-of-Delivery Comparison**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time of Delivery (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck</td>
<td>30</td>
</tr>
<tr>
<td>Ship (DR)</td>
<td>45</td>
</tr>
<tr>
<td>Rail</td>
<td>50</td>
</tr>
<tr>
<td>Ship (EJ)</td>
<td>60</td>
</tr>
</tbody>
</table>
Three Mode Emissions Calculator

Activity-based emissions model (bottom-up emissions calculation) jointly developed by RIT and Univ. of Delaware

Emissions calculated using basic principles of physics such as energy, materials content in fuels, engine efficiency

\[ Emission_{pollutant} = Activity \times Emission \text{ Factor}_{pollutant} \]

**Truck:** grams per TEU-mile
- Miles Per Gallon
- TEU Capacity
- Tons Per TEU
- Sulfur Content

**Ship:** grams per TEU-mile
- Speed
- Engine HP
- Load Factor
- TEU Capacity
- Tons Per TEU
- Sulfur Content

**Rail:** grams per TEU-mile
- Speed
- Engine HP
- Load Factor
- TEU Capacity (Well Cars* Well Car Capacity)
- Tons Per TEU
- Sulfur Content
California-specific application of GIFT
Preparation, importing and processing data in ArcGIS

RESEARCH METHODOLOGY
Structure and use of the GIFT model

Freight Transportation Data
- Transportation Network Geospatial Data
  - Highways, Railroads, Waterways
  - Multimodal transfer facilities

Vehicle and Facility Emissions and Operations Data
- Trucks, Trains, Ships
- Ports, Rail yards, Distribution centers

Freight Flow Data
- Originations/ Destinations
- Volumes

Scenario Configuration Data
- Network Configuration
  - Select cost attributes to compare
  - Select cost attributes to minimize

Find Least “Cost” Routes

Geospatial Intermodal Freight Transportation (GIFT) Analysis

Scenario Data Comparison and Analysis for Case Studies

Scenario Analysis Results

Source: (J.S. Hawker, et al., 2010)
Methodology
Gathering Data

• Commodity Flow Survey 2007
  – National freight flow figures which include estimated shipping volumes (value, tons, and ton-miles) by commodity and mode of transportation at varying levels of geographic detail
  – Lists freight tonnage between the major O-D pairs

• Port Generated Traffic- US Army Corps of Engineers 2007
  – Waterborne container traffic for US Port/ Waterway 2007

• Cambridge Systematics Origin-Destination (O-D) Database
  – Disaggregated Freight Analysis Framework 2.2 (FAF 2) data at a county level
  – FAF2 data publicly available and built from CFS and other data sources
Route Identification Method
Building a multiple O-D framework
Plural methods for allocating freight flows
Approaches to distributing freight using CFS data

Outside CA, freight split evenly between destinations in the “Remainder of” regions in the states
## Methodology

### Emissions Assumptions

<table>
<thead>
<tr>
<th>Mode Type/Spoke Type</th>
<th>CO2 Emissions by Mode Type (g/TEU-Mile)</th>
<th>Intermodal Transfer CO2 Emissions by Spoke Type (g/TEU)</th>
<th>Mode Attributes</th>
</tr>
</thead>
</table>
| Truck MY 1998-02     | 830                                    | 9200                                                   | • Fuel Economy: 6 MPG  
                           |                                        |              | • TEU Capacity: 2  
                           |                                        |              | • Tons Per TEU: 10  
                           |                                        |              | • Engine Efficiency: 42%  
                           |                                        |              | • Fuel Type: Distillate Diesel with 15ppm Sulfur |
| Rail Tier 1 Line Haul | 320                                    | 4100                                                   | • Speed: 25 mph  
                           |                                        |              | • Engine HP: 8000  
                           |                                        |              | • Load Factor: 70%  
                           |                                        |              | • Engine Efficiency: 42%  
                           |                                        |              | • TEU Capacity: 400  
                           |                                        |              | • Tons Per TEU: 10  
                           |                                        |              | • Fuel Type: Distillate Diesel with 15ppm Sulfur |
| Ship ‘Dutch Runner’   | 410                                    | 2500                                                   | • Speed: 13.5 mph  
                           |                                        |              | • Engine HP: 3070  
                           |                                        |              | • Load Factor: 80%  
                           |                                        |              | • Engine Efficiency: 40%  
                           |                                        |              | • TEU Capacity: 220  
                           |                                        |              | • Tons Per TEU: 10  
                           |                                        |              | • Fuel Type: Marine Diesel with 5000 ppm Sulfur |
Analyzing the benefits of a Modal Shift in Freight

RESULTS AND ANALYSES
Least-Time Freight Flow Results

From Ports

To Ports
Least-CO$_2$ Scenario Results

From Ports

To Ports
Air Basin Allocation Example

Least Time

Least CO₂
Air Basin Emissions Allocation Change
(difference between “least-time” and “least CO₂” routing in GIFT)
## Emissions Variation By Air Basin due to Modal Shift

<table>
<thead>
<tr>
<th>Air Basin</th>
<th>Total Least-time Scenario CO₂ Emissions (MT)</th>
<th>Total Least-CO₂ Scenario CO₂ Emissions (MT)</th>
<th>Difference in CO₂ Emissions due to Modal Shift (MT)</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Coast</td>
<td>375,866</td>
<td>149,421</td>
<td>226,445</td>
<td>-60%</td>
</tr>
<tr>
<td>San Joaquin Valley</td>
<td>178,572</td>
<td>58,690</td>
<td>119,882</td>
<td>-67%</td>
</tr>
<tr>
<td>Mojave Desert</td>
<td>120,951</td>
<td>60,908</td>
<td>60,043</td>
<td>-50%</td>
</tr>
<tr>
<td>San Francisco Bay</td>
<td>67,983</td>
<td>31,173</td>
<td>36,810</td>
<td>-54%</td>
</tr>
<tr>
<td>San Diego County</td>
<td>24,044</td>
<td>3,471</td>
<td>20,573</td>
<td>-86%</td>
</tr>
<tr>
<td>Sacramento Valley</td>
<td>34,912</td>
<td>16,948</td>
<td>17,964</td>
<td>-51%</td>
</tr>
<tr>
<td>Salton Sea</td>
<td>48,900</td>
<td>41,672</td>
<td>7,228</td>
<td>-15%</td>
</tr>
<tr>
<td>Northeast Plateau</td>
<td>8,644</td>
<td>3,994</td>
<td>4,650</td>
<td>-54%</td>
</tr>
<tr>
<td>Mountain Counties</td>
<td>6,536</td>
<td>3,517</td>
<td>3,019</td>
<td>-46%</td>
</tr>
<tr>
<td>North Coast</td>
<td>814</td>
<td>376</td>
<td>438</td>
<td>-54%</td>
</tr>
<tr>
<td>Great Basin Valleys</td>
<td>480</td>
<td>345</td>
<td>135</td>
<td>-28%</td>
</tr>
<tr>
<td>Lake County</td>
<td>36</td>
<td>17</td>
<td>19</td>
<td>-53%</td>
</tr>
<tr>
<td>Lake Tahoe</td>
<td>23</td>
<td>22</td>
<td>1</td>
<td>-4%</td>
</tr>
<tr>
<td>South Central Coast</td>
<td>14,986</td>
<td>17,164</td>
<td>(-2,178)</td>
<td>15%</td>
</tr>
<tr>
<td>North Central Coast</td>
<td>3,100</td>
<td>6,240</td>
<td>(-3,140)</td>
<td>101%</td>
</tr>
<tr>
<td><strong>Total in-state</strong></td>
<td><strong>885,847</strong></td>
<td><strong>393,958</strong></td>
<td><strong>491,889</strong></td>
<td><strong>-56%</strong></td>
</tr>
</tbody>
</table>
# Comparison of Emissions Across Scenarios

## Least Time Scenario

<table>
<thead>
<tr>
<th>Emission Attributes</th>
<th>Total Emissions From All Port Traffic (MT)</th>
<th>Total Emissions From Traffic from Port (MT)</th>
<th>Total Emissions From Traffic towards Port (MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Port of LA-LB</td>
<td>Port of OAKLAND</td>
</tr>
<tr>
<td>CO₂</td>
<td>2,885,360</td>
<td>1,707,510</td>
<td>102,759</td>
</tr>
</tbody>
</table>

## Least CO₂ Scenario

<table>
<thead>
<tr>
<th>Emission Attributes</th>
<th>Total Emissions From All Port Traffic (MT)</th>
<th>Total Emissions From Traffic from Port (MT)</th>
<th>Total Emissions From Traffic towards Port (MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Port of LA-LB</td>
<td>Port of OAKLAND</td>
</tr>
<tr>
<td>CO₂</td>
<td>1,182,764</td>
<td>694,997</td>
<td>45,337</td>
</tr>
</tbody>
</table>

## Total Emissions Comparison

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>2,885,360</td>
<td>1,182,764</td>
<td>1,702,596</td>
<td>59.01%</td>
</tr>
</tbody>
</table>
SUMMARY
Conclusion

• Idealized use of least-CO$_2$ routing constraints illustrates emissions savings can be achieved through modal shifts.

• Total emissions reductions of 1.7 MMT (~0.5 MMT within California) of CO$_2$ achievable through a nationwide modal shift of West-Coast ports generated goods movement.

• Results are based on assumption that all port-related goods movement occurs through truck (not adjusted for amount moving through rail and other modes).

• Results have relevance for consideration of system-wide improvements that may achieve energy savings, CO$_2$ reductions, and associated benefits for air quality.
Summary

• GIFT can be used for systems analysis to model energy and environmental attributes of freight flow
• Model parameters can be changed to represent real-world policy scenarios
• GIFT can provide an estimate of the emissions saved through goods movement system improvements

• FUTURE IMPROVEMENTS
  – Utilize Multi-Criteria Optimization Approaches
  – Incorporate real-world speeds
  – Inclusion of geospatial gradient data
  – Better emissions calculations
  – Account for Delays in networks
Questions?