IMPROVING THE ENERGY EFFICIENCY & ENVIRONMENTAL PERFORMANCE OF GOODS MOVEMENT

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## Acknowledgements

- Although I am presenting today, much of the material was developed jointly with Dr. James J. Corbett, University of Delaware.

- I am indebted to the faculty and students in the Laboratory for Environmental Computing and Decision Making at RIT, including Bryan Comer, Chris Prokop, Dr. Scott Hawker, and Dr. Karl Korfmacher.

My Job Today

- Present energy and environmental attributes of goods movement from multiple modes
- Discuss benefits from shifting from high energy-intensity modes to low energy-intensity modes
- Assess overall opportunities for mode-shifting in a larger systems context
- Provoke policy-focused discussion

Working Hypothesis

- We can solve a large part of the energy and environmental problems of freight transportation by moving goods off trucks and onto trains and ships.

Overview of Goods Movement

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

Source: Corbett and Winebrake, 2009.
U.S. Freight Transport by Mode, 1980-2030

Source: Bureau of Transportation Statistics Table 1-46b (1980-2006); AEO 2009 (derived, 2007-2030).

Projected Energy Use in U.S. Freight Transport, 2006-2030

AAGR:
- Freight truck = 1.3%
- Freight rail = 0.9%
- Air (freight carriers) = 2.8%
- Domestic shipping = 0.9%

Source: AEO 2009 Table 45

Source: AEO 2009, Table 45.
Percentage of Energy-Related Transportation CO2 Emissions by Mode, 2008

- Light-Duty Vehicles: 57.8%
- Shipping, Domestic: 12%
- International: 3.1%
- Rail, Freight: 2.2%
- Rail, Passenger: 0.3%
- Freight Trucks: 18.3%
- Bus Transportation: 1.0%
- Commercial Light Trucks: 2.1%
- Recreational Boats: 0.9%
- Air: 9.8%
- Military Use: 2.8%
- Lubricants: 0.3%

Total emissions from transportation: ~1.9 GtCO2eq/yr
Total emissions from all energy sectors: ~5.9 GtCO2eq/yr

Source: AEO 2009, Table 19.

Modal Comparisons


Note: These represent top-down averages and should not be used for blanket modal comparisons!

Source: Transportation Energy Data Book 27

Range of typical CO2 efficiencies for various cargo carriers

- Crude
- LNG
- General Cargo
- Reefer
- Chemical
- Bulk
- Container
- LPG
- Product
- RoRo / Vehicle
- Rail
- Road

**NOTE:** Impacts are a function of many factors related to route and modal characteristics.


Some Examples Using GIFT

The Geospatial Intermodal Freight Transportation (GIFT) model is a model jointly developed by the Rochester Institute of Technology and the University of Delaware, with funding support from US DOT/MARAD, Great Lakes Maritime Research Institute, ARB, among others.

Connect Multiple Transportation Mode Networks at Intermodal Transfer Facilities

Define Economic, Energy, Time and Environmental Costs of Traversing Each Network Segment and Transfer

<table>
<thead>
<tr>
<th>Truck Segment “Costs”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
</tr>
<tr>
<td>----------</td>
</tr>
</tbody>
</table>

ESRI ArcGIS Network Analyst finds “Shortest” (least cost) routes.

Montreal to Cleveland (Ship 1)  Montreal to Cleveland (Ship 2)
Emissions and Time of Delivery Tradeoffs
Montreal to Cleveland

CO₂ (kg)

<table>
<thead>
<tr>
<th>Mode</th>
<th>CO₂ (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck</td>
<td>400 kg</td>
</tr>
<tr>
<td>Ship (DR)</td>
<td>200 kg</td>
</tr>
<tr>
<td>Rail</td>
<td>80 kg</td>
</tr>
<tr>
<td>Ship (EJ)</td>
<td>40 kg</td>
</tr>
</tbody>
</table>

Time-of Delivery (hrs)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time-of Delivery (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck</td>
<td>40 hrs</td>
</tr>
<tr>
<td>Ship (DR)</td>
<td>60 hrs</td>
</tr>
<tr>
<td>Rail</td>
<td>80 hrs</td>
</tr>
<tr>
<td>Ship (EJ)</td>
<td>80 hrs</td>
</tr>
</tbody>
</table>

CO₂ Comparison

- Truck Only
- Rail Only
- Ship-Truck
- Rail-Truck

CO₂ Comparison

Opportunities for Mode Shifting

The IF-TOLD Mitigation Framework: A Context for Mode Shifting Discussions

- The IF-TOLD “six-legged cow”:
  - **Intermodalism/mode-shifting** – use of efficient modes
  - **Fuels** – use of low carbon fuels
  - **Technology** – application of efficient technologies
  - **Operations** – best practices in operator behavior
  - **Logistics** – improve supply chain management
  - **Demand** – reduce how much STUFF we consume

Even a six-legged cow can move all legs – dynamic, balancing!

Opportunities for Mode-Shifting

\[ \Delta E_{ij} = \sum_k \left[ W_{ik} \cdot c_{ijk} \cdot f_{ijk} \cdot p_{ijk} \left( E_i - E_j \right) \right] \]

\( \Delta E_{ij} \) = energy savings due to modal shift from \( i \) to \( j \)
\( W_{ik} \) = work done by mode \( i \) for commodity \( k \) (ton-miles)
\( c_{ijk} \) = shipment compatibility fraction of \( i \) to \( j \) for \( k \) (cargo)
\( f_{ijk} \) = shipment feasibility fraction of \( i \) to \( j \) for \( k \) (infrastructure)
\( p_{ijk} \) = shipment practicality fraction of \( i \) to \( j \) for \( k \) (economic)
\( E_i \) = energy intensity factor for \( i \) (Btu/ton-mile)
\( E_j \) = energy intensity factor for \( j \) (Btu/ton-mile)

Also need to account for intermodal transfer penalties.

Insights into $c_{ijk}$ – Cargo Characteristics

Percentage of Goods Movement in U.S. by Commodity (Sample) and Mode (2002 CFS Data)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Truck</th>
<th>Rail</th>
<th>Water</th>
<th>Other/Unknown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Misc. manufactured products</td>
<td>1.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elect. and electrical equip.</td>
<td>1.0%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Nonmetallic mineral products</td>
<td>4.3%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Basic chemicals</td>
<td>3.7%</td>
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<td></td>
<td></td>
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<tr>
<td>Coal</td>
<td>21.9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonmetallic minerals</td>
<td>1.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel and crushed stone</td>
<td>3.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other agricultural products</td>
<td>3.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cereal grains</td>
<td>8.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Live animals and live fish</td>
<td>0.1%</td>
<td></td>
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</tr>
</tbody>
</table>

Source: CFS 2002, Ton-Miles by Commodity and Mode

Insights into $f_{ijk}$ – U.S. Intermodal Infrastructure

Average Miles per Shipment by Mode for the U.S. (2007)


Estimating Mode Shifting Potential

\[ \Delta E_{ij} = \sum_k W_{ik} \cdot c_{ijk} \cdot f_{ijk} \cdot p_{ijk}(E_i - E_j) \]

Consider total ton-miles as a gridded box, where each cell is equivalent to 1%. 

Assume that about 50% of the cargo currently moved by truck is compatible with rail or ship due to physical properties, safety, loading logistics, etc. \([c_{ijk} \sim 0.50]\)
Estimating Mode Shifting Potential

\[ \Delta E_{ij} = \sum_k W_{ik} \cdot c_{ijk} \cdot f_{ijk} \cdot p_{ijk} (E_i - E_j) \]

Assume that of the cargo that is compatible, infrastructure can only serve 70% of the ton-miles in the short term \([f_{ijk} \sim 0.70]\)

Estimating Mode Shifting Potential

$$\Delta E_{ij} = \sum_k [W_{ik} \cdot c_{ijk} \cdot f_{ijk} \cdot p_{ijk} (E_i - E_j)]$$

Under these assumptions, there is potential to move ~5% of the total ton-miles (~12% of truck ton-miles) from truck to rail/ship. If truck is ~5 times more energy intense than rail/ship, then this implies ~8% reduction in energy consumption.

Average distance by truck is 200 miles. Assume that ~50% of the ton-miles shipped > 200 miles and 25% are > 500 miles. Assume economic possibility exists for mode shifting for 35% of total truck trips. [$p_{ijk} \sim 0.35$].

## Policy Options

<table>
<thead>
<tr>
<th>Policy Options</th>
<th>Intermodalism</th>
<th>Fuel</th>
<th>Technology</th>
<th>Operations</th>
<th>Logistics</th>
<th>Demand</th>
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<td>Efficiency standards</td>
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<td>Infrastructure investment</td>
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<td>Demand management</td>
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<td></td>
<td>●</td>
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</tbody>
</table>

Conclusion

Conclusion

- Modal shifts offer large side-by-side benefits
- System benefits vary depending on vessel, vehicle, locomotive, and route characteristics and are constrained by compatibility, feasibility, and practicality – research needed here
- Suite of policy options should be considered recognizing freight sector as a system
- Wedge analysis needed for freight sector that looks at potential for the IF-TOLD set of elements


