A Comparative Analysis of Ships v. Trucks to Transport Cargo along the Great Lakes
Sustainable Intermodal Freight Transport Research Program

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Goods Transport

- Great Lakes shipping occurs across three modes
  - Railroad
  - Ship
  - Truck
- Each has pros and cons, and intermodal combinations offer flexibility and efficiency
- One intermodal ship is SS Badger carferry.
SS Badger

• Started as a railcar ferry in 1953
• Now ferries cars, passengers, and cargo
• Engines declared a mechanical engineering landmark by the American Society for Mechanical Engineers
• Ship itself placed on the National Register of Historic Places
• Only coal-fired steamship in US
Outline

• What did we study?
• How did we analyze it?
• What were our results?
• How robust are they?
• What are our conclusions?
What we studied

- Emissions of 6 criteria pollutants
  - Carbon dioxide ($\text{CO}_2$), Sulfur oxides (SOx), Nitrogen oxides (NOx), particulate matter (PM$_{10}$), methane ($\text{CH}_4$), and carbon monoxide (CO)
- Looked at current emissions from both truck and Badger
- Compared to a fuel switch from coal
  - Intermediate Fuel Oil (IFO), Marine Distillate Oil (MDO), Compressed Natural Gas (CNG), Liquified Natural Gas (LNG) and a biodiesel blend (BD20)
**Truck Route (Intermodal Scenario)**
- Total Distance: ~45 miles
- Travel Time: ~0.8 hrs

**Ferry Route (Intermodal Scenario)**
- Total Distance: ~62 miles
- Travel Time: ~4 hrs

**Truck Route (Intermodal Scenario)**
- Total Distance: ~260 miles
- Travel Time: ~4.5 hrs

**All-Truck Route (Scenario B)**
- Total Distance: ~500 miles
- Travel Time: ~8 hrs

**All-Truck Route (Scenario A)**
- Total Distance: ~620 miles
- Travel Time: ~10.5 hrs

**Legend**
- Red: Truck Route
- Green: Ferry Route
Emissions Estimation Basics

General equation used:

\[ P_{ij} = E_j \cdot EF_{ij} \]

where \( P_{ij} \) represents pollutant of type \( i \) for mode \( j \) in kg/segment; \( E_j \) represents energy consumption for mode \( j \) in BTU/segment; and \( EF_{ij} \) represents an emissions factor for pollutant \( i \) for mode \( j \) in mass/energy unit (e.g., g/BTU or g/hp-hr).
Results for Different Pollutants

- **CO**
- **SO**
- **NO**
- **PM**
- **CH**
- **CO**
Example of sensitive assumptions

- Current configuration is for 12 tractor trailers
- Capacity is 180 “Vehicle Units”
  - One tractor trailer = 4 Vehicle Units
- Assuming only 12 trailers would assign all pollution to those trailers
- Therefore assumed 45 trailers on board

- Is this a good assumption?
  - More freight than normal max (Calculated emissions too low)
  - We allocate ALL emissions to payload (Calculated emissions too high)

- Our “best estimate” for study was 117 TEUs,
  - May be conservatively high (optimized for freight)
## Sensitivity Analysis

### Ranges for vessel and vehicle characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low</th>
<th>Best</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Vessel Trips</td>
<td>445</td>
<td>445</td>
<td>460</td>
</tr>
<tr>
<td>Vessel Engine Load Factor (%)</td>
<td>50</td>
<td>73</td>
<td>80</td>
</tr>
<tr>
<td>Vessel Boiler-Engine Efficiency (%)</td>
<td>17</td>
<td>22</td>
<td>45</td>
</tr>
<tr>
<td>Vessel Payload Capacity (TEU)</td>
<td>31.2</td>
<td>117</td>
<td>117</td>
</tr>
<tr>
<td>Ship Speed (knots)</td>
<td>15.9</td>
<td>18.0</td>
<td>18.6</td>
</tr>
<tr>
<td>Truck efficiency (mpg)</td>
<td>5.5</td>
<td>6</td>
<td>7.2</td>
</tr>
<tr>
<td>Truck Payload Capacity (TEU)</td>
<td>1</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>All-truck route distance (miles)*</td>
<td>500</td>
<td>620</td>
<td>650</td>
</tr>
</tbody>
</table>
SS Badger CO$_2$ performance using current steam propulsion

Primary inputs of influence
1. Vessel utilization (payload capacity)
2. Truck utilization (payload capacity)
3. Route distance (truck options)
4. Truck fuel efficiency
Sensitivity results

Considering potential for improved thermal efficiency

Improving fuel economy on the SS Badger (e.g., plant thermal efficiency) would substantially transform the analysis.

Dieselization or other prime mover modernization can be coupled with alternative fuels to outperform all-truck route.
Discussion Summary

- **Study scope**
  - Compare environmental performance of alternative routes (all-truck v. intermodal) under various fuel scenarios

- **Methods**
  - Apply GIFT model and SS Badger data to explore routes and environmental performance
  - Apply sensitivity analysis to identify high-leverage variables
Results Summary

- Current all-truck route outperforms intermodal scenarios in most cases

- Results are case-specific to 1950s steam-propulsion technology and route served by SS Badger and do not include total fuel cycle emissions

- Sensitivity analysis reveals opportunities for natural gas or MDO with or without new engine designs, payload configuration, etc.

- Natural-gas-fueled engine propulsion can perform at lower $\text{CO}_2$ emissions than all-truck route
Conclusions

• Natural gas shows promise as a marine fuel for Great Lakes vessels

• Technology modernization can accompany a fuel-transition for Great Lakes (such as scrubbers, dieselization, payload configuration)

• A Great Lakes shipping transition to natural gas fuels will need to be strategic, and analyses like this study can serve as important decision support role for GLMRI and industry partners

• Adding a total fuel cycle analysis to this work will provide additional insights into the role of alternative fuels
Thank you