Supporting Sustainable Design of Transportation Infrastructure: Developing Integrated Decision-Making Models

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Northwestern University

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Motivation

- **Practical**: Assist decision-makers to be able to understand and value the environmental costs of their transportation infrastructure and vehicles

- **Theoretical**: A gap exists between the tools used by decision makers and the descriptive methods used to measure environmental impacts

- **Contribution**: Integrate environmental impacts within prescriptive modeling and optimization frameworks
Conceptual Model: Integrated Decision-Making

- Environmental Life Cycle Assessment
- Optimization/Decision-Making Models
- Tradeoffs between Environmental/Economic Factors
- Multi-Dimensional Return on Investment
Life Cycle Assessment

- Life Cycle Assessment measures environmental impacts over the lifetime of the vehicle – including indirect impacts from the supply chain.
- Measures include, but are not limited to, Greenhouse Gas (GHG) emissions, water use, and energy consumption.
Life Cycle Assessment

- Philips and Northwestern 2009 CO2 Emissions Reporting Project
  - Project scope: Capture shipping emissions from all Philips North America Shipments
  - Focus on ‘Tailpipe’ CO2 Emissions from shipments
### 2009 Philips & Northwestern CO2 Reporting Project:

#### Source of Uncertainty | Likely Direction of True Emissions | Implications for the 2009 CO2 Reporting Project
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Missing Data (Section 6.1 and 6.2) |  | • Only 22 of 58 sources provided complete 2009 shipment data  
• Magnitude of missing data unknown  
• Some data reports revenue figures only

Missing/Misreported Weight (Section 6.3.1) |  | • Large amount of shipments with missing or "0" weight from Powertrack  
• Issues verifying weight data from YRC, Ryder

Missing/Misreported Mode (Section 6.3.2) |  | • Large amount of shipments with mode not available from YRC, Powertrack  
• All non-specified parcel shipments considered ground

Missing/Misreported Distance (Section 6.3.4) |  | • Estimation techniques may over or under-estimate true distance  
• No distance or unreliable distance reported from Powertrack and Trendset

Aggregation Bias (Section 7.2.1) |  | • Different types of shipments (long-haul, short-haul, parcel, drayage) are aggregated together, resulting in bias in reported emissions  
• Distance and weight are aggregated by mode and data source

Aggregate Emissions Factors (Section 7.2.2) |  | • Emissions factors do not account for carrier/modal/shipment variation  
• Multi-modal aspects (ground component of air) not considered

Distance-weight based emissions factors (Section 7.2.3) |  | • Fuel-use factors provide more reliable emissions estimates than distance-weight based factors  
• Fuel-use unavailable or not used

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### 2 Types of Sources of Uncertainty:

- **Data Collection**
- **CO2 Emissions Calculations**
2009 Challenges

Shipping Data Collection
- Missing data and data errors
- Missing or Mis-reported mode

CO2 Emissions Calculations
- Aggregation Bias
- Distance/Weight Calculations

Proposed 2010 Mitigation Strategies

- Ongoing or quarterly data collection; Standardize format
- Include multi-modal shipments and modal variation (ie. “Long-Haul Air Parcel”)
- Increase detail in shipment reporting
- Transition to fuel-use based methodology

Goal: Best-Practice Standards throughout the Supply Chain
**Transit Bus Fleeting Project**

- **Question:** What is the optimal bus fleet mix for an urban transit operator?

- **Scope:** Incorporation of Life Cycle Assessment, Monetary Costs, and Level of Service variables into the Decision-Making Process.
Developing Integrated Decision-Making Models for Transit Operators

Cost Profiles of Alternative Fuel Buses (Baseline: Diesel Bus)

<table>
<thead>
<tr>
<th>Transit Bus Fleet Mix</th>
<th>Economic Costs</th>
<th>Environmental Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>Purchase of Infrastructure or Vehicles</td>
<td>Manufacturing Emissions, End of Life options</td>
</tr>
<tr>
<td>Operational</td>
<td>Fuel, Labor, Maintenance</td>
<td>Tailpipe Emissions, Fuel Consumption</td>
</tr>
</tbody>
</table>

Bus Type 1

<table>
<thead>
<tr>
<th>COSTS</th>
<th>Econ.</th>
<th>Enviro.</th>
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<tbody>
<tr>
<td>Cap.</td>
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<tr>
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Bus Type 2

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Bus Type 3

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</table>
Life-Cycle Assessment of Alternative Fuel Transit Buses

Manufacturing a Transit Bus: Energy Use
(Average U.S. Energy Mix)
Conclusions and Implications

• Transportation infrastructure (and other products) should be assessed according to the environmental and economic costs over the entire life-cycle
• We use an framework that incorporates both life-cycle assessment and optimization models to examine the tradeoffs between multi-dimensional costs
• These are necessary steps that lead us towards the big questions:
  • How much do we pay for sustainability?
  • How much should we pay for sustainability?
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Life-Cycle Assessment of Alternative Fuel Transit Buses

Manufacture of a Transit Bus: Greenhouse Gas Emissions

- Diesel
- Compressed Natural Gas
- Hydrogen Fuel Cell
- Diesel-Electric Hybrid
2009 Philips & Northwestern CO2 Reporting Project:

Goal: Capture 90% of Shipments

Consumer Lifestyles
- Parcel
- Ryder
- Powertrack

Lighting
- Powertrack
- LTI
- YRC
- Genlyte

Healthcare
- Parcel
- YRC

Canadian (All Divisions)
- Parcel