Closing the loop on supply chains…

Dr. Jane Ammons
School Chair and Professor of ISyE
Georgia Tech

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Objectives for today’s class

• Understand how efficient closed loop supply chains
  – Benefit the environment
  – Provide economic development opportunity ($, jobs)
• Conceptualize effective infrastructure
  – Collection, transportation, processing
  – Sufficient volumes are critical for economic viability
• See how industrial engineers have the creativity and good analysis tools to design and operate closed loop supply chains
  – Must address uncertainty
  – Must capture perspective
Research Team

Faculty:
• Jane Ammons
  CoE/Ga Tech
  Atlanta, GA  30332-0360
  jane.ammons@coe.gatech.edu
  404-894-2364

• Matthew Realff
  ChBE/Ga Tech
  Atlanta, GA  30332-0100
  matthew.realff@chbe.gatech.edu
  404-894-1834

Graduate Students:
• Chan-joo Lee, Josh Pas, I-Hsuan Hong, Tiravat “To” Avasapookee, Jing Wei, Chanjoo Lee
• Wuthichai Wongthatsanekorn, David Newton
• Juan Martin Vannicola (ITBS Argentina)
• Devon Oudit (Fulbright program)
• Ken Gilliam (Army)

Industrial Collaborators
• CARE (Carpet Recovery America Effort)
• Reboot, Zentech, Molam
• Carpet and electronics manufacturers

State & Federal Government
• CCACIT
• Georgia DNR, P2AD
• NSF under grant Grants # DMI-0200162, SBE-0123532, DMI-0620191
• EPA

Research team in action
Used Carpet

- 4.7 billion lbs of carpet are disposed of in the US each year
- Landfill costs ~ $100 Million
- Value of material ~ $2.8 Billion/yr

Opportunity

Dalton Landfill
Carpet Manufacturing Waste Monofill Area
Used Electronics

• 300 million personal computers have been “retired” to storage in basements, closets, warehouses, etc.
• 315 – 680 million will be obsolete in next few years

Opportunity !!!!

Used Electronics

• Environmental concerns
  – Lead, arsenic, cadmium, mercury, cobalt
  – Landfill space
  – Export to developing countries where processing may cause problems
Some background

**PBS** – FRONTLINE – World Stories from a Small Planet

*Ghana: Digital Dumping Ground*

June 23, 2009


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**Drivers for Reverse Systems**

- 6-7 x World GDP growth in the next 50 years (in constant dollars)
- 5-6 x production capacity for commodities
- 3.5 x increase in world energy demand
- 33% of world energy demand is used in industrial production

**How will we provide these materials and energy?**

(The U.S. Consumes 26% of world oil production but has only 2% of its known reserves. The next highest consumer is Japan with 7%.)

**Will we continue to meet our material needs through extraction?**

Regulatory and disposal costs are additional drivers.
Differences between Reverse and Forward Supply Chains

In the reverse supply chain,
- The network has many sources upstream and narrows to a few customers downstream.
- Diverse materials are produced by disassembly and physicochemical processes.
- The final materials are low volume compared to the forward production system.
- Pricing scheme is different from the forward supply chain.
- Uncertainty in *supply – amounts, condition, content* is at the beginning of the chain.

RPS Infrastructure

<table>
<thead>
<tr>
<th>Source of e-scrap</th>
<th>Collecting center</th>
<th>Processing center</th>
<th>Sink of e-scrap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Source - TV, CPU, Monitor</td>
<td>Municipal Collection Sites</td>
<td>Commercial Processing Sites</td>
<td>Material Recyclers</td>
</tr>
<tr>
<td>Commercial Source - CPU, Monitor</td>
<td>Non-profit Recycling Sites</td>
<td>Smelters</td>
<td>End Customers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Landfill</td>
</tr>
</tbody>
</table>

End Customers

Material Recyclers
RPS Infrastructure Decisions

• Location, number and size of collection sites and processing sites
• Allocation of functions in the reverse chain to geographic locations
• Modes of transportation connecting sites
• Flows for products and materials through potential task network
• Amount of material allocation to each potential end-use

Georgia’s Computer Equipment Disposal and Recycling Council

• Created by the Georgia legislature in 2002 for a 5 year term
• Mandate to investigate and advise legislature and governor on E-scrap policy
• Uses operations research models to evaluate potential alternatives
• Monthly hearings
12 DCA Regions in State of Georgia

Service regions are defined by Georgia’s Department of Community Affairs (DCA)

Locations of Alternative Sites
(Georgia Case Study)

- 12 Municipal collection sites
- 6 Non-profit collection & processing sites (NP)
- 15 Commercial processing sites (A)
- 1 Prison processing site (PR)
- 1 Processing site for products from large business (AA)
# Georgia e-scrap Supply Estimates

<table>
<thead>
<tr>
<th>Region</th>
<th>Supply for TVs (lbs)</th>
<th>Supply for Monitors (lbs)</th>
<th>Supply for CPUs (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>133,610</td>
<td>216,400</td>
<td>272,720</td>
</tr>
<tr>
<td>2</td>
<td>87,236</td>
<td>141,290</td>
<td>178,060</td>
</tr>
<tr>
<td>3</td>
<td>657,000</td>
<td>1,064,130</td>
<td>1,341,040</td>
</tr>
<tr>
<td>4</td>
<td>77,388</td>
<td>125,340</td>
<td>157,960</td>
</tr>
<tr>
<td>5</td>
<td>83,970</td>
<td>136,000</td>
<td>171,400</td>
</tr>
<tr>
<td>6</td>
<td>84,318</td>
<td>136,570</td>
<td>172,110</td>
</tr>
<tr>
<td>7</td>
<td>83,339</td>
<td>134,980</td>
<td>170,110</td>
</tr>
<tr>
<td>8</td>
<td>67,680</td>
<td>109,620</td>
<td>138,150</td>
</tr>
<tr>
<td>9</td>
<td>52,283</td>
<td>84,680</td>
<td>106,720</td>
</tr>
<tr>
<td>10</td>
<td>67,605</td>
<td>109,500</td>
<td>137,990</td>
</tr>
<tr>
<td>11</td>
<td>69,912</td>
<td>113,240</td>
<td>142,700</td>
</tr>
<tr>
<td>12</td>
<td>104,024</td>
<td>168,480</td>
<td>212,330</td>
</tr>
<tr>
<td>13*</td>
<td>0</td>
<td>90,000</td>
<td>90,000</td>
</tr>
<tr>
<td>14*</td>
<td>0</td>
<td>90,000</td>
<td>90,000</td>
</tr>
<tr>
<td>Total (lbs)</td>
<td>1,568,365</td>
<td>2,720,230</td>
<td>3,381,290</td>
</tr>
</tbody>
</table>

* Outside Georgia

# RPS Infrastructure Determination Model (RPS)

**Maximize:** Net Profit \((\text{Revenues} - \text{Operating and Fixed Costs})\)

**Subject to:**

Supply and Demand
based on supply and demand at each source and sink point.

Flow balances between sites
based on material consumed and produced by the tasks
located at those sites.

Upper and lower bounds
on storage, transportation and processing of material at sites.

Logical constraints on sites, such as the need to open
a site before allowing tasks to be located there.
Experimental Design

- Four factors and two levels for each factor
  - Participation rate
    - Levels: 20% and 30%
  - CRT recycler option
    - Levels: with all CRT recyclers and with only OH CRT recycler
  - TV usability rate
    - Levels: 10% and 30%
  - CPU & monitor usability rate
    - Levels: (CPU 40%, monitor 40%) and (CPU 20%, monitor 20%)

- Total scenarios conducted: $2 \times 2 \times 2 = 16$

Model Scenarios

<table>
<thead>
<tr>
<th>Useable %: TV: 30% CPU: 40% Monitor: 40%</th>
<th>CRT Recyclers</th>
<th>Useable %: TV: 10% CPU: 40% Monitor: 40%</th>
<th>CRT Recyclers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Participation</td>
<td>Sc 1</td>
<td>Percent Participation</td>
<td>Sc 5</td>
</tr>
<tr>
<td>20%</td>
<td>Sc 2</td>
<td>20%</td>
<td>Sc 6</td>
</tr>
<tr>
<td>30%</td>
<td>Sc 3</td>
<td>30%</td>
<td>Sc 7</td>
</tr>
<tr>
<td></td>
<td>Sc 4</td>
<td></td>
<td>Sc 8</td>
</tr>
</tbody>
</table>

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<tr>
<th>Useable %: TV: 30% CPU: 20% Monitor: 20%</th>
<th>CRT Recyclers</th>
<th>Useable %: TV: 10% CPU: 20% Monitor: 20%</th>
<th>CRT Recyclers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Participation</td>
<td>Sc 9</td>
<td>Percent Participation</td>
<td>Sc 13</td>
</tr>
<tr>
<td>20%</td>
<td>Sc 10</td>
<td>20%</td>
<td>Sc 14</td>
</tr>
<tr>
<td>30%</td>
<td>Sc 11</td>
<td>30%</td>
<td>Sc 15</td>
</tr>
<tr>
<td></td>
<td>Sc 12</td>
<td></td>
<td>Sc 16</td>
</tr>
</tbody>
</table>
Robust Decisions in the Case Study

Scenario 1
RPS Optimal Solution

Scenario 2
RPS Optimal Solution

Scenario 16
RPS Optimal Solution

A robust solution under every scenario

Discrete Robust RPS Optimal Solution

Robust Solution for 16 Scenarios

- Municipal collection sites
- Non-profit collection & processing sites (NP)
- Commercial processing sites (A)
- Processing site for products from large business (AA)
Net Profit of Scenario 1 ~ 16

Texas case study by Assavapokee’s student, Pantanat Wayuparb

Pre-selection of Site Locations

Population
- 0-25,000 (155 counties)
- 25,001-100,000 (64 counties): One-day
- 100,001-500,000 (24 counties): Regular/One-day
- 500,001-3,600,000 (9 counties): Hub/Regular/One-day
Disaggregation of RPS Infrastructure

Collection Phase
- Source of e-scrap
  - Residential Source
    - TV, CPU, Monitor
  - Commercial Source
    - CPU, Monitor
- Collecting center
- Municipal Collection Sites
- Non-profit Recycling Sites

Processing Phase
- Processing center
- Commercial Processing Sites
- End Customers
- Material Recyclers
- Landfill
- Recycler for Large Commercial Sources

Comparison of Objective Function Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Objective Value</th>
<th>Aggregate</th>
<th>Disaggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.98%</td>
<td>0.27%</td>
<td>-0.30%</td>
</tr>
<tr>
<td>2</td>
<td>0.13%</td>
<td>0.91%</td>
<td>-0.85%</td>
</tr>
<tr>
<td>3</td>
<td>-0.13%</td>
<td>0.21%</td>
<td>-0.18%</td>
</tr>
<tr>
<td>4</td>
<td>-0.13%</td>
<td>0.18%</td>
<td>-0.18%</td>
</tr>
<tr>
<td>5</td>
<td>-0.13%</td>
<td>0.06%</td>
<td>-0.05%</td>
</tr>
<tr>
<td>6</td>
<td>-0.13%</td>
<td>-0.05%</td>
<td>-0.05%</td>
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<tr>
<td>7</td>
<td>-0.13%</td>
<td>-0.05%</td>
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<tr>
<td>8</td>
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<td>10</td>
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<td>14</td>
<td>-0.13%</td>
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<td>15</td>
<td>-0.13%</td>
<td>-0.05%</td>
<td>-0.05%</td>
</tr>
<tr>
<td>16</td>
<td>-0.13%</td>
<td>-0.05%</td>
<td>-0.05%</td>
</tr>
</tbody>
</table>
Many studies have been addressed on reverse logistics systems in a *centralized* way (Barros et al. 1998; Fleischmann et al. 2000; Guide and Harrison 2003; Shih 2001). Sometimes we need to understand the differences in the system behaviors and to engineer mechanisms for decentralized systems to exhibit good overall system performance.
The Solution Algorithm

Given the source response, I don’t know who will give me the best price offer? What’s the individual price range each one will offer? Let me minimize my maximum loss when I design flow contract with each individual one?

Comparison of Results for Centralized and Decentralized Models

A three-tier example with five collectors, three consolidation sites, and four processors is examined.

One may overestimate the system profit by the model if it is assumed that the decisions are made centrally in a system of independent entities.

The potential factors: price uncertainty and double marginalization

Centralized model (a quadratic programming model)

Maximize: Net Profit Quadratic term w.r.t. price (Revenues – Acquired and Transportation Costs)

Subject to: Flow conservation between sites Capacity limitations (Transportation and processing)
Summary

• Efficient reverse production systems
  – Benefit the environment
  – Provide economic development opportunity ($, jobs)

• Effective infrastructure required
  – Collection, transportation, processing
  – Sufficient volumes are critical for economic viability

• Industrial engineers have creativity and good analysis tools to design and operate closed loop supply chains
  – Must address uncertainty
  – Must capture perspective (centralized, decentralized…)