Closing the loop on supply chains…

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

December 3, 2013

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 Martín 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
- CCACTI
- 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


---

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
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

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  
(Revenues – 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 \times 2 = 16

Model Scenarios

<table>
<thead>
<tr>
<th>Percent Participation</th>
<th>Useable %: TV: 30% CPU: 20% Monitor: 40%</th>
<th>CRT Recyclers</th>
<th>Useable %: TV: 10% CPU: 20% Monitor: 40%</th>
<th>CRT Recyclers</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>Sc 1</td>
<td>With all CRT Recyclers</td>
<td>Sc 5</td>
<td>With all CRT Recyclers</td>
</tr>
<tr>
<td>30%</td>
<td>Sc 2</td>
<td>With only CRT recycler in OH</td>
<td>Sc 6</td>
<td>With only CRT recycler in OH</td>
</tr>
<tr>
<td>20%</td>
<td>Sc 3</td>
<td>With all CRT Recyclers</td>
<td>Sc 7</td>
<td>With only CRT recycler in OH</td>
</tr>
<tr>
<td>30%</td>
<td>Sc 4</td>
<td>With only CRT recycler in OH</td>
<td>Sc 8</td>
<td>With only CRT recycler in OH</td>
</tr>
<tr>
<td>20%</td>
<td>Sc 9</td>
<td>With all CRT Recyclers</td>
<td>Sc 13</td>
<td>With all CRT Recyclers</td>
</tr>
<tr>
<td>30%</td>
<td>Sc 10</td>
<td>With only CRT recycler in OH</td>
<td>Sc 14</td>
<td>With only CRT recycler in OH</td>
</tr>
<tr>
<td>20%</td>
<td>Sc 11</td>
<td>With all CRT Recyclers</td>
<td>Sc 15</td>
<td>With only CRT recycler in OH</td>
</tr>
<tr>
<td>30%</td>
<td>Sc 12</td>
<td>With only CRT recycler in OH</td>
<td>Sc 16</td>
<td>With only CRT recycler in OH</td>
</tr>
</tbody>
</table>
Robust Decisions in the Case Study

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
- Commercial Processing Sites
  - Non-profit Recycling Sites
  - Recycler for Large Commercial Sources

Processing Phase
- Processing center
- Sink of e-scrap
  - Material Recyclers
  - End Customers
  - Landfill

Comparison of Objective Function Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Objective Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.96%</td>
</tr>
<tr>
<td>2</td>
<td>0.97%</td>
</tr>
<tr>
<td>3</td>
<td>1.13%</td>
</tr>
<tr>
<td>4</td>
<td>1.87%</td>
</tr>
<tr>
<td>5</td>
<td>2.1%</td>
</tr>
<tr>
<td>6</td>
<td>-0.3%</td>
</tr>
<tr>
<td>7</td>
<td>-0.3%</td>
</tr>
<tr>
<td>8</td>
<td>0.96%</td>
</tr>
<tr>
<td>9</td>
<td>-1.8%</td>
</tr>
<tr>
<td>10</td>
<td>-2.35%</td>
</tr>
<tr>
<td>11</td>
<td>-3.35%</td>
</tr>
<tr>
<td>12</td>
<td>-3.36%</td>
</tr>
<tr>
<td>13</td>
<td>3.24%</td>
</tr>
<tr>
<td>14</td>
<td>0.25%</td>
</tr>
<tr>
<td>15</td>
<td>0.25%</td>
</tr>
<tr>
<td>16</td>
<td>0.25%</td>
</tr>
</tbody>
</table>

Graph showing comparison of objective function results with aggregate and disaggregate scenarios.
Computation Time Comparison

Centralized versus Decentralized Perspectives

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.

Each entity acts in a self-interested manner with respect to its own objective and firm constraints. No, or limited, information sharing is allowed.
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 (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…)