Lecture #18

ERDM

Prof. John W. Sutherland

Feb. 20, 2004
Disassembly Sequence
(“and or” diagram)
Disassembly Sequence (network model)

Separate subassemblies in [ ]
Disassembly Analysis

- The network model describes the disassembly process flow.
- Disassembly steps (e.g., remove part A) are characterized by arcs in the figure.
- Disassembly configurations (e.g., C is separate from parts A+B+D) appear as nodes in the figure.
- Industrial Engineering (Operations Research) techniques can be used to analyze the system.
Selecting a Disassembly Sequence

- Let’s say we take the product apart a few times and we try to explore each of the pathways in the network model (sometimes referred to as a directed graph).

- We can establish a time for each disassembly operation (or perhaps even time distributions).

- Alternatively, there are handbooks that list the times required to perform certain operations.

- We could select the pathway that produces the minimum time.
Minimum Completion Time

[Diagram of a network with nodes labeled A, B, C, D, E, F, G, and T, and edges with numerical values indicating time or duration]
Minimum Time Problem

- The minimum time problem we have just solved is also referred to as the “shortest path problem”. Floyd’s algorithm -- Dijkstra’s algorithm
- For each node, we consider all ways to arrive at that node, and we select the way that is the minimum.
- By-product: Best way to get to every configuration.
- In principle, we could use this approach to figure out the best way to completely disassemble the entire product.
Partial Disassembly

• Is complete disassembly the best way to go?

• Maybe, if the product is designed correctly, we can quickly extract the parts that are
  - Undamaged
  - Of high value
  - Hazardous

• Then, recycle the material that remains in the product.

• What impact does partial disassembly have on our network model??
Modeling Partial Disassembly

- Associated with each disassembly activity is a cost. This cost includes the time to complete the task as well as other activity-related costs. (Costs are negative)

- At some nodes in our network model, we free up an individual part. When this happens, it is expected that revenue will be generated. (Revenue is positive)

- The challenge is then to figure out in which order to remove parts, and when (and if) to stop.
Maximum Profit Partial Disassembly

A: 12, B: 10, C: 3, D: 3

- A, B, C, D
  - [C] [A, B, D]
    - [C] [A, D] [B]
      - [A] [B] [C] [D]
        - A: 12, B: 10, C: 3, D: 3
    - [C] [A, B] [D]
      - [C] [A, D] [B]
        - A: 12, B: 10, C: 3, D: 3
      - [A] [B] [C] [D]
        - A: 12, B: 10, C: 3, D: 3
  - [D] [A, B, C]
    - [D] [A, C] [B]
      - [A] [B] [C] [D]
        - A: 12, B: 10, C: 3, D: 3
    - [D] [A, B, C]
      - [D] [A, C] [B]
        - A: 12, B: 10, C: 3, D: 3
Disassembly Paths

Number of possible disassembly paths grows quickly!!
Let’s use our network model instead.
Maximum Profit

Node that frees up a component

Environmentally Responsible Design & Manufacturing (MEEM 4685/5685)
Dept. of Mechanical Engineering - Engineering Mechanics
Michigan Technological University

© John W. Sutherland
What if the product has been used and has undergone damage/wear?
We may need to select disassembly path based on an initial inspection.
Recap

We’ve examined the influence of product design characteristics on environmental performance:

- Concept design
- Material selection
- Geometric features
- Part dimensions
- Assembly/Disassembly

Now, given this background, what must a designer do to reduce environmental impact?
Concept Design

We talked about using QFD to incorporate the “voice of the environment” in the design process.

- Most importantly -- while maximum degrees of freedom remain, CONSIDER ENVIRONMENTAL CONSEQUENCES!!

- Think “out of the box” -- how can customer needs be met from a minimum energy, minimum resource, minimum waste standpoint?

- Ideas: analogies in nature, brainstorming, etc.
Concept Design (cont.)

- What is the plan for the product at the end of its life??
  - Recycling?
  - Remanufacturing?
  - Reuse?
  - No plan? or Disposal?

- Product stewardship
  - Selling use versus selling a product
  - Lease programs
  - Increased software content (less hardware)
  - Reverse logistics (recovery infrastructure) in place?
Material Selection

Desirable characteristics of materials:

- Abundant, nontoxic, nonregulated materials
- Avoid complex materials, coatings, surface treatments
- Natural materials over synthetic materials
- Minimize the use of different materials
- Try to use recycled materials when possible
### Material Abundance

<table>
<thead>
<tr>
<th>Classification</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infinite supply</td>
<td>Ar, Br, Ca, Cl, Kr, Mg, N, Na, O, Rn, Si, Xe</td>
</tr>
<tr>
<td>Ample supply</td>
<td>Al(Ga), C, Fe, H, K, S, Ti</td>
</tr>
<tr>
<td>Adequate supply</td>
<td>I, Li, P, Rb, Sr</td>
</tr>
<tr>
<td>Potentially limited supply</td>
<td>Co, Cr, Mo(Rh), Ni, Pb (As, Bi), Pt (Ir, Os, Pd, Rh, Ru), Zr (Hf)</td>
</tr>
<tr>
<td>Potentially highly limited supply</td>
<td>Ag, Au, Cu (Se, Te), He, Hg, Sn, Zn (Cd, Ge, In, Tl)</td>
</tr>
</tbody>
</table>
Materials -- Energy Requirements

Energy Input (GJ/Mg)

<table>
<thead>
<tr>
<th>Metal</th>
<th>Primary Production</th>
<th>Secondary Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>31</td>
<td>9</td>
</tr>
<tr>
<td>Copper</td>
<td>91</td>
<td>13</td>
</tr>
<tr>
<td>Aluminum</td>
<td>270</td>
<td>17</td>
</tr>
<tr>
<td>Zinc</td>
<td>61</td>
<td>24</td>
</tr>
<tr>
<td>Lead</td>
<td>39</td>
<td>0</td>
</tr>
<tr>
<td>Titanium</td>
<td>430</td>
<td>140</td>
</tr>
</tbody>
</table>

- Energy advantage of recycled materials
# Materials -- Solid Waste

<table>
<thead>
<tr>
<th>Metal</th>
<th>Ore (Tg)</th>
<th>Avg. Grade (%)</th>
<th>Residues (Tg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>910</td>
<td>0.91</td>
<td>900</td>
</tr>
<tr>
<td>Iron</td>
<td>820</td>
<td>40.0</td>
<td>490</td>
</tr>
<tr>
<td>Lead</td>
<td>120</td>
<td>2.5</td>
<td>117</td>
</tr>
<tr>
<td>Aluminum</td>
<td>100</td>
<td>23.0</td>
<td>77</td>
</tr>
<tr>
<td>Nickel</td>
<td>35</td>
<td>2.5</td>
<td>34</td>
</tr>
<tr>
<td>Others</td>
<td>925</td>
<td>8.1</td>
<td>850</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2910</strong></td>
<td></td>
<td><strong>2460</strong></td>
</tr>
</tbody>
</table>

- Destruction of local habitats
Geometric Features

Remember discussion of reprocessability index

- Complexity makes reuse / remanufacturing more difficult. But assembly and disassembly may be simplified.
- Large part size promotes recycling, but uses more resources.
- Reduce stresses (avoid thin sections & stress risers) -- enhance product life -- maintain product value.
- Mating/contact surfaces -- discourage reuse and remanufacturing -- replaceable inserts an option.
- Removable features favored.
Part Dimensions

Remember discussion of Product Value Model

- Adopt the long term view -- want to think about the WHOLE USAGE STAGE.

- Maximize product life and consumer satisfaction over the life of the product. Want maximum value.

- Remember product performance degrades over time.

- Product-to-product variability increases over time.
Product Configuration

- How are the components within a product related to one another? Assembly/Disassembly

- We want to promote disassembly.
  - Tall hierarchy -- Modular Product Design
  - Flat hierarchy -- may favor replacement of individual components
  - Controlled or Destructive Disassembly
  - Single direction for insertion/removal

Remember discussion of liaison diagrams and network model for selecting disassembly order